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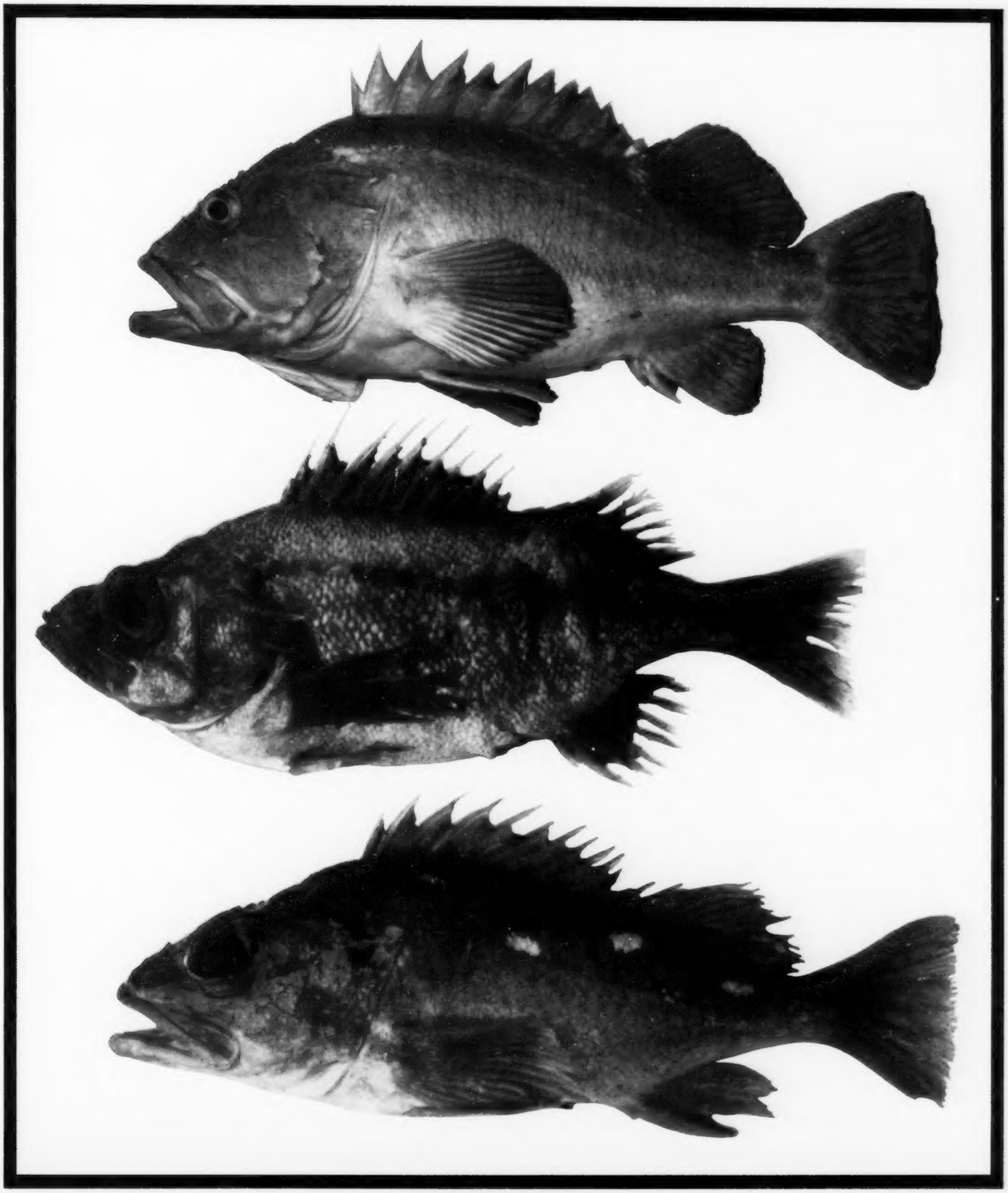

Sebastes

Marine Fisheries REVIEW

On the cover, top to bottom: Yelloweye rockfish, *Sebastes ruberrimus*; splitnose rockfish, *S. diploproa*; and rosethorn rockfish, *S. helvomaculatus*. Photos by and courtesy of Donald E. Kramer, University of Alaska, Anchorage, Alaska.

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Simulated Economic Impact of TED Regulations on Selected Vessels in the Texas Shrimp Fishery

JOY CLARK, WADE GRIFFIN, JERRY CLARK, and JAMES RICHARDSON

Introduction

Shrimp fishermen trawling in the Gulf of Mexico and the south Atlantic inadvertently capture and kill sea turtles which are classified as endangered species. Recent Federal legislation requires the use of a Turtle Excluder Device (TED) which, when placed in the shrimp trawl, prevents turtle mortality. However, the shrimp industry has been concerned about the possible impact of the TED upon vessel shrimp catch.

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ABSTRACT—Shrimp fishermen trawling in the Gulf of Mexico and south Atlantic inadvertently capture and kill sea turtles which are classified as endangered species. Recent legislation requires the use of a Turtle Excluder Device (TED) which, when in place in the shrimp trawl, reduces sea turtle mortality. The impact of the TED on shrimp production is not known. This intermediate analysis of the TED regulations using an annual firm level simulation model indicated that the average Texas shrimp vessel had a low probability of being an economic success before regulations were enacted. An assumption that the TED regulations resulted in decreased production aggravated this condition and the change in Ending Net Worth and Net Present Value of Ending Net Worth before and after a TED was placed in the net was significant at the 5 percent level.

However, the difference in the Internal Rate of Return for the TED and non-TED simulations was not significant unless the TED caused a substantial change in catch. This analysis did not allow for interactions between the fishermen in the shrimp industry, an assumption which could significantly alter the impact of TED use on the catch and earnings of the individual shrimp vessel.

This analysis was designed to address this issue by evaluating the impact of the TED regulations upon the economic viability of representative shrimp vessels in the Texas shrimp fishery.

This analysis, however, does not explicitly consider the interactive aspects of the shrimp fishery, both among the vessels and between the vessel catch and remaining shrimp stock. An implicit assumption of this analysis is that the individual vessel's fishing behavior would not change as a result of the TED regulations, in response to either increases or decreases in catch per tow. Rather, this analysis is based on the resultant impact on the catch of the representative vessel in the Texas shrimp fishery given all the interactive effects. That is, after all other considerations, if the vessel catch has changed, what is the impact on the economic viability of the vessel? Finally, this is an intermediate analysis of the impact of the TED regulations. Future analysis should be directed at examining the interactive effects within the fishery.

History

In 1981 the National Marine Fisheries Service (NMFS), as the result of an ongoing research and development program, introduced a shrimping gear design aimed at reducing the capture of sea turtles. This device would be sewn into a shrimp trawl (Fig. 1) and was designed to provide a way for sea turtles to exit the trawl. Because of its proposed function, it was called a Turtle Excluder Device (TED) (Watson et al., 1985).

All sea turtles are listed as endangered or threatened by the Endangered Species Act. Under this Act it is illegal to import, export, take, possess, sell, or transport endangered species without a permit unless these activities are specifically allowed by regulation (USDC, 1978; Yaffee, 1982). Five species of sea turtles are caught in shrimp trawls in the waters of the southeast United States. They are the loggerhead, *Caretta caretta*; Kemp's ridley, *Lepidochelys kempi*; green, *Chelonia mydas*; leatherback, *Dermochelys coriacea*; and hawksbill, *Eretmochelys imbricata* (Dean and Steinbach, 1981; Anonymous[1]). In 1978, when the green and loggerhead sea turtles were listed under the Endangered Species Act (the other three species were listed in earlier rulemakings), the problem of incidental take of these species in the shrimp fishery was addressed in a Final Environmental Impact Statement (USDC, 1978). At that time, methods to reduce the incidental take were not available.

In 1983, NMFS began a formal program to encourage voluntary adoption of TED's by the shrimp industry. Through the voluntary program, TED's were constructed under contract and distributed to shrimpers who agreed to use them. Modification and evaluation of the TED continued, resulting in a smaller, lighter, collapsible NMFS TED, as well as other non-NMFS TED's. Despite numerous extension programs, publicity and train-

[1]Anonymous. 1983. Environmental assessment of a program to reduce the incidental take of sea turtles by the commercial shrimp fleet in the southeast United State. U.S. Dep. Commer., NOAA, NMFS Southeast Reg. Off., St. Petersburg, Fla., 20 p.

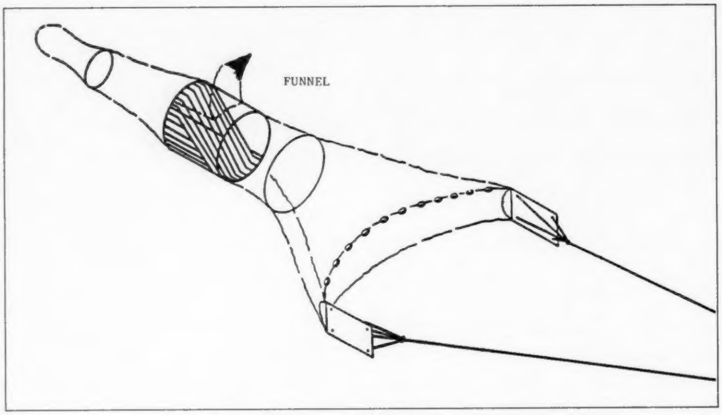

Figure 1.—Position of the TED in the shrimp trawl.

ing activities, the voluntary program was not effective (Anonymous[2]). As of late 1986, less than 3 percent of the shrimp fleet had used or continued to use a TED (Oravetz[3]).

Specific regulations concerning use of TED's were developed in 1986 during mediation between members of the southeastern U.S. shrimp industry and interested members of the environmental community. Proposed regulations were published in the March 1987 Federal Register and final regulations were published in the July 1987 Federal Register. As summarized by the National Marine Fisheries Service (Anonymous[4]), as of 1 May 1989 in offshore waters, use of the TED was to be required of all vessels measuring 25 feet or longer. For vessels of less than 25 feet in length, the option of towing 90 minutes was available. There are seasonal requirements by region, with Canaveral and southwest Florida vessels required to pull the TED year-round, Gulf vessels required to pull the TED March though November, and Atlantic vessels from May through August. Inshore regulations have similar seasonal requirements but all shrimp trawls must either use a TED or limit tow time to 90 minutes.

Turtle Excluder Devices

Testing conducted off Cape Canaveral, Fla., prior to 1988 (Table 1) identified four TED's which satisfactorily excluded turtles from commercial shrimp nets: 1) The standard 30-inch opening and 25-inch opening NMFS TED's, 2) the "Georgia" TED, 3) the "Cameron" TED, and 4) the "Matagorda Bay" TED. In the time period subsequent to 1988, additional devices have been approved but they are not considered as part of this analysis.

The NMFS and Cameron TED's are three-dimensional, implying that a section of the net must be removed to install the device. The NMFS devices are rectangular in shape whereas the Cameron TED is circular (Fig. 2). The Georgia and Matagorda TED's are two-dimensional and are sewn directly into the net. The Georgia TED has a long oval shape with parallel bars creating a barrier across the surface of the device. The Matagorda TED is rectangular and also has parallel bars which function as a barrier to entry into the cod end of the trawl (Fig. 3). The positioning of the opening in the trawl, which allows turtles and other large organisms to escape, varies by TED. The NMFS and the Matagorda devices have top openings. The Georgia TED has a

Table 1.—Summary of testing conducted to determine capabilities of four Turtle Excluder Devices. Sources: Text footnotes 4, 5, 6, 8, and 10.

Test and type of TED	No. of tows	Turtles caught (no.)		Shrimp catch (lb.)		By-catch (lb.)	
		Control	TED	Control	TED	Control	TED
Cape Canaveral tests[1]							
NMFS TED	10	14	0	26.00	24.00	7,488	4,164
Cameron TED	10	21	0	26.75	26.50	4,551	3,026
Georgia TED	10	16	0	13.75	17.25	5,275	4,014
Matagorda TED	10	17	0	31.75	29.50	7,771	4,312
North Carolina Sea Grant							
NMFS TED with 45° grid angle	8			696[2]	291	158[3]	55.50
NMFS TED with 37° grid angle	10			1,393	1,513	73.10	42.65
St. Simon's Island							
NMFS TED	18			158.00	175.38		
Georgia TED	18			159.88	156.88		
Matagorda TED	18			143.25	194.75		
Cameron TED	18			175.88	200.75		
Texas testing[4]							
Std. NMFS TED	49			3,073	3,127	186.8	230.3
Mini NMFS TED	5			170	249	0	2.2
Georgia Jumper	14			753	793	29.6	40.1

[1]Data recorded for 7 tows w/TED, while 10 tows were recorded for control.
[2]Measured as number of shrimp rather than pounds of shrimp caught.
[3]Measured in kg.
[4]By-catch measured in bushels.

[2]Anonymous. 1986. Report from the turtle excluder device workshop. U.S. Dep. Commer., NOAA, NMFS, Southeast Fish. Cent., Pascagoula, Miss., 15 p.

[3]Chuck Oravetz, National Marine Fisheries Service, NOAA, Southeast Regional Office, St. Petersburg, Fla. Presentation at TED meetings in Pascagoula, Miss., Oct. 1986.

[4]Anonymous. 1989. Summary of TED/tow time regulation. U.S. Dep. Commer., NOAA, NMFS Southeast Reg. Off., St. Petersburg, Fla. 1 p.

bottom opening and the Cameron TED can be used with either a bottom or top opening.

Meanwhile, TED development and use has also been proceeding in other nations. In July 1986, following a publicity and coordination trip in March, a workshop and vessel demonstration was held in Mazatlan, Mex. In Indonesia, over 1,000 TED's are in use in the western area on joint-venture Japanese vessels. Indonesia has sent fishing gear experts for training at the NMFS Harvesting Systems Division, Mississippi Laboratories (USDC, 1985).

Tests for Shrimp Exclusion

NMFS Tests

As early as September 1983, NMFS was testing its new TED to determine the impact on shrimp catch and by-catch reduction. These tests were directed at evaluating the TED design modifications to improve finfish by-catch reduction rates. The TED used in these experiments was the original solid NMFS TED (Anonymous[5]).

NMFS continued testing and improving the TED, and additional tests were made in 1984. From July through September, the FRV *Jeanie* conducted tests off Florida, Alabama, and Mississippi. Initially, tests were directed at performance of several different designs of the NMFS TED. These included: Fiberglass frame and PVC joints, steel-frame collapsible, aluminum frame, and miniature-frame TED. PVC joints of the aluminum-frame TED's were found to be too weak to withstand normal shrimping operations.

Other cruises were made to compare shrimp retention rates of various TED's vs. a control net without a TED. These cruises were done both day and night and incorporated different types of finfish deflectors (Hummer wire, types A and H and solid bar, type D) (Anonymous[6]).

[5]Anonymous. 1983. Cruise Report for FRS OREGON II Cruise 137 - 9/6/83 - 9/21/83. Dep. Commer., NOAA, NMFS Southeast Fish. Cent., Pascagoula, Miss., 4 p.
[6]Anonymous. 1984. Cruise reports for FRV JEANIE. U.S. Dep. Commer., NOAA, NMFS Southeast Fish. Cent., Pascagoula, Miss., 4 p.

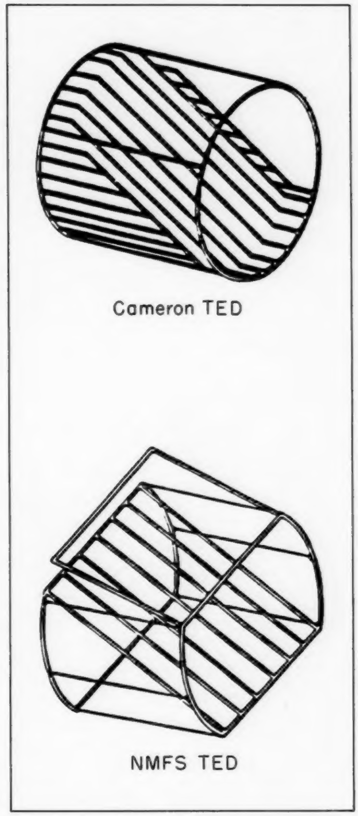

Figure 2.—General schematic of Cameron TED (circular) and NMFS TED (rectangular).

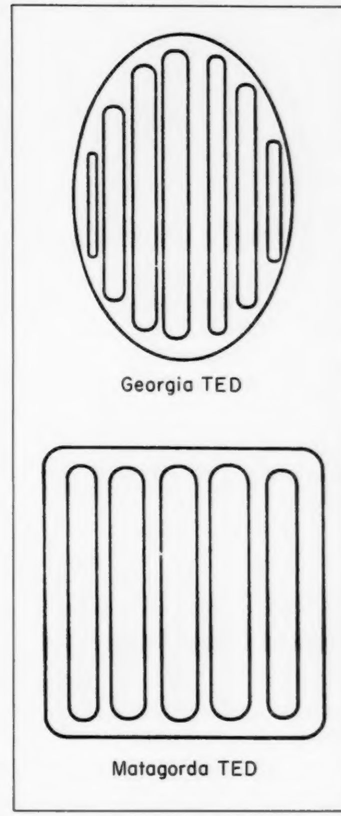

Figure 3.—General schematic of the Georgia TED (circular) and Matagorda TED (rectangular).

North Carolina Test

The University of North Carolina Sea Grant program was also involved in testing shrimp and finfish retention rates of the various TED's. In April and May 1986, two cruises were made aboard the *Carolina Coast* (Table 1) (Anonymous[7]). Of the two NMFS TED's tested, the one with the 37° grid angle appeared to be more effective at eliminating by-catch with no overall loss of shrimp. Although by-catch was measured in kilograms, shrimp catch was measure in numbers of individual shrimp. Large quantities of shrimp were not encountered, possibly due to the half-hour tow limitation. This made it difficult to measure the impact on shrimp catch.

In July 1986, under the auspices of the University of North Carolina Sea Grant Program, tests were conducted on the "Georgia Jumper" (Anonymous[8]). A total of 24 tows were made by the *Carolina Coast*. Nineteen tows were compared with a standard net and 5 tows were

[7]Anonymous. 1986. Cruise Report for CAROLINA COAST Cruises: TED Testing - April 28-30, 1986. Univ. N.C. Sea Grant, N.C. Mar. Resour. Cent., Atlantic Beach, N.C., 2 p.

[8]Anonymous. 1986. Cruise Report for CAROLINA COAST Cruise: TED Testing - July 14-18, 1986. Univ. N.C. Sea Grant, N.C. Mar. Resour. Cent., Atlantic Beach, N.C., 2 p.

compared with the NMFS TED. Several adjustments were made to the TED before it was operating properly. When all 19 tows were considered, the TED experienced an 18 percent shrimp loss, however, for the 15 tows when the TED was operating properly there was only a 9 percent shrimp loss. The tested TED was very effective in reducing horseshoe crab, cannonball jellyfish, stingray, and tunicate catches, with an overall by-catch reduction of 24 percent (21 percent for the 15 tows above). For the 5 tows against the NMFS TED there was an overall 9 percent shrimp loss with 40 percent less by-catch (Anonymous[9]).

Georgia Test

The Marine Extension Service of the Georgia Sea Grant College Program conducted tests off Georgia on the four TED's tested at the Cape Canaveral channel: Georgia Jumper, Cameron TED, Matagorda TED, and NMFS Collapsible TED without funnel. The purpose of these tests was to determine shrimp exclusion rates of TED's (Anonymous[10]).

A total of 72 double-rig trawls were conducted with 9 port and 9 starboard tows conducted with each of the four different TED's (Table 1). Sampling was conducted 3-4 miles east of the south portion of St. Simon's Island, Ga., in 30 feet of water. The Georgia Jumper had a 1.9 percent gain compared with a standard trawl without a TED. The NMFS TED had a 9.9 percent loss, the Cameron TED a 12.4 percent loss, and the Matagorda TED a 26.4 percent loss (Anonymous[11]).

Texas Test

Tests with the four TED's presently certified for use were conducted in Texas waters using both bay and Gulf vessels to determine the impact of TED devices on Texas shrimp production (Graham[12]). Many of the tows done in Texas were faulty, for one reason or another, and thus, rigorous statistical analyses have not been carried out (Table 1). The results of this testing were useful in indicating the learning process which must occur when a TED is introduced into the trawl.

TED Impacts

When reviewing testing that has been completed on various TED's, a wide range of results is apparent. Tests have been conducted in different areas off the eastern and southern U.S. coasts using different types of vessels and different TED's. The approach to testing is consistent, i.e., simultaneous drags with a control net and a TED net, but the gear and nets vary across all experiments. As a result, it is not surprising to find that TED capabilities varied with the experiments.

Cape Canaveral testing certified four TED's as possessing the capability of "kicking out" sea turtles from the trawl. Further testing conducted by the NMFS determined finfish reduction capability of the TED and helped in refinement of the TED. Finfish reduction rates as high as 80 percent were recorded during the day although night reduction rates were lower. There was no significant reduction in shrimp catch during these tests (Anonymous[13]).

Testing by the University of North Carolina Sea Grant program resulted in extreme values for average shrimp loss (58 percent) over all tests. The TED was mounted in the net at a 45° angle; subsequent North Carolina testing showed this to be an inappropriate angle. In addition, the results were for experiments where the total number of shrimp encountered were small, and this makes any analysis suspect. Further testing with a 37° angle for TED installation gave a shrimp increase of 8.6 percent, and more shrimp were consistently encountered during these experiments.

Tests off St. Simon's Island, Ga., were the only ones to use all four certified TED's. The Georgia Jumper had a 1.9 percent production gain, whereas the other three TED's showed losses (NMFS a 9.9 percent loss, Cameron a 12.4 percent loss, and Matagorda a 26.4 percent loss). However, only 18 tows were made with each TED.

The final series of tests, off the Texas coast, are reported here. Again, the variety of vessels used and variation in equipment, as well as change in location, made accurate interpretation of this data difficult. In addition, a report by Byrne, et. al.[14] argues that the experimental design of the TED testing does not allow specific shrimp retention rates to be identified.

Economic Impact of TED's

Method of Analysis

The intent of this analysis was to examine the impact of TED regulations on the earning capacity of a single representative vessel. The method of analysis is to simulate conditions that are representative of a vessel in the Texas' Gulf shrimp fishery, using the firm-level simulation model FLEETSIM, under the proposed TED regulations (Clark et al[15]). FLEETSIM is a firm level, recursive, simulation model which simulates the annual production, costs, and income aspects of a fleet, by vessel, over a multi-year planning horizon.

FLEETSIM is capable of simulating a hypothetical fleet for 1-10 years. The model recursively simulates a typical fleet by using the ending financial position for year one as the beginning position for the second year, and so on. FLEETSIM does not include an overall objective function to be optimize, but rather analyzes the outcome of a given set of input data and assumptions for a typical fleet. Accounting equations and identities con-

[9]Anonymous. 1986. Cruise Report for CAROLINA COAST Cruises: TED Testing - April 28-30, 1986. Univ. N.C. Sea Grant, N.C. Mar. Resour. Cent., Atlantic Beach, N.C., 2 p.

[10]Anonymous. 1987. Preliminary results from shrimp retention studies on four different turtle excluder devices off the Georgia Coast. Univ. Ga. Sea Grant, Mar. Ext. Serv., Brunswick, 15 p.

[11]Anonymous. 1987. Preliminary results from shrimp retention studies on four different turtle excluder devices off the Georgia Coast. Univ. Ga. Sea Grant, Mar. Ext. Serv., Brunswick, 15 p.

[12]G. Graham. 1986. Summary of TED cruise reports #1 - #10 and individual cruise accountings. Tex. Agric. Ext. Serv., Tex. A&M Univ., Coll. Sta., Tex., 11 p.

[13]Anonymous. 1984. Cruise reports for FRV JEANIE. U.S. Dep. Commer., NOAA, NMFS Southeast Fish. Cent., Pascagoula, Miss., 4 p.

[14]R. Byrne, W. Griffin, and J. Clark. 1987. Four TED's analysis of variance. Nat. Resour. Work. Pap. Ser. Nat. Resour. Workgroup, Dep. Agric. Econ., Tex. A&M Univ., Coll. Sta., 15 p.

[15]J. L. Clark, J. W. Richardson, and C. J. Nixon. 1987. Description of FLEETSIM: A general firm level policy simulation model for a shrimp fleet. Nat. Resour. Work. Pap. Ser. Nat. Resour. Workgroup, Dep. Agric. Econ., Tex. A&M Univ., Coll. Sta., 50 p.

stitute most of the computational components of the model.

Procedure

Three separate simulations were conducted in an effort to analyze the impact of the TED regulations. These three models were: 1) Historical, 2) Baseline, and 3) TED Simulations.

The first FLEETSIM analysis examined the historical situation in the Gulf industry from 1978 to 1986. No analysis is included for bay vessels on the assumption that bay shrimpers will take advantage of the 90-minute tow time exception and will not be required to use TED's. This analysis was deterministic and was conducted to obtain a starting financial position for the baseline simulation. The program was run using actual values for changes in inflation, interest rates, landings and prices, and production costs for a representative vessel. In addition, the model began with a new vessel in 1978 and was run without considering income tax. Therefore, all values generated represent a before-tax situation.

The second FLEETSIM analysis involved the development of a baseline simulation model for the fishery. The first year of analysis for this model was 1987. The purpose of the baseline model was to predict what would occur in the industry without TED regulations. The result of the baseline simulations was later used to determine the impact of the TED regulations. The third step, following the development of the baseline simulation model and estimates of future costs and returns for the representative vessel, was to build effects of TED regulations into the model.

Data

Production and budget information for Gulf shrimpers was obtained from interviews conducted with members of the Texas Gulf shrimp industry (Anonymous[16]). This information included past production, costs and returns, and changes in number and size of vessels for the period 1969-86. Vessel size and construction varied considerably from 20- to 30-foot wood up to 90-foot steel ones. Some firms had vessels that were 20-30 years old, while others culled vessels after 10 years.

Baseline and TED simulation analyses were stochastic, as opposed to deterministic. In Baseline and TED policy analyses, pounds landed by the vessel were stochastically set about a mean value, based on a 5 year (1982-86) average of fishery landings. Prices were similarly set but included an adjustment based on changes in the Consumer Price Index. No attempt was made to account for any price changes which might occur if the use of a TED leads to a decline in total production of shrimp, Gulfwide. Price would likely increase if production declined, especially for large shrimp which are the mainstay of the Gulf shrimp fleet analyzed here.

In an effort to make stochastic variables a function of actual relationships in the industry, an analysis of historical price and landing trends for Gulf shrimp vessels was conducted. To generate random landings and prices, it was necessary to provide cumulative deviations around mean values for these variables. This was accomplished by regressing average annual landings and prices against time and taking resulting deviations and dividing them by the value for mean landings and prices. An additional explanation of this procedure can be found in the FLEETSIM user manual.

Values for future interest rates and inflations rates, associated with prices and production costs, were obtained from COMGEM[17], a macroeconomic simulation model developed by Penson, Hughes, and Romain. The "best" predictions available were annual predictions of inflation rates approximating 4 percent for 1987 through 1990 and, thereafter a constant of 4 percent. The cumulative deviations of these macroexogenous variables, i.e., interest rates and fuel prices, were generated based on historical data in much the same manner as those for landings and prices.

Assumptions

The impact of the TED on the production capability of the vessel is potentially manyfold. It is expected that initially there will be a negative impact while the fisherman learns how to use the device. This "learning period" will vary by vessel and captain and, therefore, a measurement of its impact is difficult.

Contributing to this measurement problem is the range of difficulty of use across various TED devices. The Georgia Jumper and Matagorda TED's are relatively simple devices, whereas the NMFS and Cameron TED's are bulky and more difficult to work with. Many vessel captains already employ some type of excluder device ("jellyball shooters") during certain portions of the year. This experience should make efficient use of a TED more likely. In this analysis, because of the inability to establish a reasonable estimate of the "learning period" impact of adopting a TED, no impact is included.

Another point is the widespread perception that some of the TED's are bulky and, therefore, unsafe to handle and may have an effect on insurance rates. Conversely, there may be positive benefits associated with the use of a TED. Improved fishing efficiency and fewer safety problems which arise from heavy bycatch, may result in favorable changes in insurance rates. No analysis is incorporated in this study because of an inability to establish a specific impact of the TED on insurance rates.

For similar reasons, issues dealing with possible improved shrimping efficiency associated with use of the TED are not dealt with in this analysis. This improved efficiency centers around possible higher percentage of shrimp in the catch when a TED is used, resulting in longer tow times, improved shrimp quality, and reduced sorting time.

A final issue is that research to date has been limited to tow-by-tow comparisons for one vessel and do not represent the situation when all vessels will pull a TED. For example, if an area of ocean bottom contains, at any one time, a fixed amount

[16]Anonymous. 1987. Regulatory impact review and regulatory flexibility analysis for regulations which require the use of turtle excluder devices by shrimpers to conserve sea turtles. U.S. Dep. Commer., NOAA, NMFS Southeast Reg. Off., St. Petersburg, Fla., 25 p.

[17]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

of shrimp, several passes through the area might catch a fixed proportion of available shrimp. If each net is catching less shrimp on the first pass (because of the TED), subsequent passes will be associated with larger remaining population level because less shrimp were taken on the previous tow. Thus, although catch per unit of effort might be reduced for a given tow because of the TED, the catch per unit of effort would not decrease as much as suggested by the sample data because more population remains for the next tow. The argument is perhaps best seen in reverse. Some of the research indicates that the use of a TED increases shrimp catch, yet it is not sensible to believe that the total shrimp catch Gulf-wide could increase annually by 5 percent if TED's are employed. The impact of TED's on the industry cannot be extrapolated from an isolated vessel pulling a TED, which has been the research to date.

The studies that have been conducted to date do not focus on the above issues and, therefore, data are limited. Although these issues are recognized as being important, they are not considered in this analysis.

It was assumed that the vessel was purchased new at the beginning of the historical simulation (1978). The vessel was of steel construction and 73 feet in length. In purchasing the vessel, it was assumed that 50 percent of the purchase price was paid down and the rest of the purchase price was financed over a 10 year period at 9 percent per annum.

To examine the impact of the TED regulations, assumptions had to be made about the impact of the TED on production capabilities of the vessels and cost of various TED devices. These assumptions were based on production impact analysis presented earlier as well as cost information obtained for the four TED devices.

Considerable differences exist in the studies that have been conducted about the impact of the TED on shrimp production. It is assumed that shrimpers will use those TED's that are most effective at retaining shrimp. The mean shrimp retention, however, has generally ranged from a small increase to about a 10 percent decrease when using a TED in those experiments where more than a few shrimp are encountered and technical difficulties are absent. Therefore, four scenarios are reported in this research: No change, a 5 percent decrease, a 10 percent decrease, and a 5 percent increase in shrimp production associated with the use of a TED. This range encompasses the mean retention of the most efficient TED's.

TED Costs

At the time of this study there were five certified TED's: the NMFS, Georgia Jumper, Cameron, Matagorda, and a "soft" TED. This paper was essentially complete before the soft TED was certified, and therefore, no economic analysis of this particular device is included. Highest estimates of acquisition costs were for the NMFS TED, with quotes between \$375 and \$475, whereas price estimates for the Georgia and the Cameron TED's ranged between \$150 and \$250 (Clark and Griffin[18]). For purposes of this analysis, each TED is assumed to cost \$300 (a number between the lesser cost TED's and the NMFS TED).

Total cost of using a TED varied depending on type of vessel and type of TED. In the Gulf it is possible to see both double-trawl and twin-trawl rigs, indicating between three and six TED's could be required for a Gulf vessel. These numbers include a spare TED for each two TED's used. The expected life of the TED is assumed to be 2 years.

The model was run for a double-trawl rig which required an investment in three TED's at a cost of \$300 per TED. This resulted in a total purchase cost for the Gulf vessel of \$900 or an annual cost of \$450.

An additional annual maintenance cost of \$50 was assumed, resulting in an annual TED cost of \$500. An accounting technique, which entered the TED cost on the cost side of the model and reduced initial cash by one-half the purchase price of the TED, forced the model to put cash aside for the purchase of a TED 2 years in the future.

[18]J. L. Clark and W. L. Griffin. 1987. Update of costs and returns for seven Texas shrimp vessels. Nat. Resour. Work. Pap. Ser. Nat. Resour. Workgroup, Dep. Agric. Econ., Tex. A&M Univ., Coll. Sta., 2 p.

Method of Evaluation

Variables used in evaluating the impact of TED regulations on the representative vessel were ending net worth in year 10, internal rate of return of the analysis, present value of ending net worth, equity-to-asset ratio and the probability net present value will be greater than zero. Net worth was determined by subtracting total liabilities from total assets. Ending net worth reflected owner's equity in the vessel and in other personal property at the end of the planning horizon. The internal rate of return is often referred to as "marginal efficiency of capital." By definition, internal rate of return is the discount rate that equates present value of benefits with the present value of costs. An investment is selected as long as internal rate of return exceeds cost of capital.

The present value technique puts the net worth at the end of the planning horizon in real dollars. The equity-to-asset ratio is one measure of solvency. A one-to-one ratio means a vessel/boat owner did not have any debt. A ratio less than one-to-one would indicate a business had not paid off all debt owed on assets (Osburn and Schneeberger, 1978).

Another issue when examining economic viability of the vessel is the probability that net present value of a stream of income during the period of analysis was greater than zero. The discount rate used for calculating net present value was set at 7 percent. It was not unreasonable to expect this rate of return on alternative investments outside the fleet. These five variables are obtained from stochastic simulations for the baseline and four TED scenarios.

Discussion of Simulation Results

Deterministic Simulation 1978-1986

A representative Gulf vessel was simulated for 9 years. An outstanding balance on the vessel of \$120,000 was financed during 10 years at a rate of 9 percent per annum. Beginning cash reserve was set at \$26,000 and resulting beginning net worth (market value) was \$117,692.

Table 2.—Annual production costs for a representative Gulf shrimp vessel (73 feet, steel hull).

Item	Cost (season total)
Ice	$ 3,106
Fuel	23,271
Repair and replacement	12,746
Other	14,063
Packing	$0.09/lb.
Dock rental	663
Insurance	7,738

Table 3.—Comparison of output variables at the end of a 10-year period across baseline and TED policy simulations for the Gulf of Mexico.

Simulation	Percent impact on shrimp production	Ending net worth	Internal rate of return	PV of ending net worth	Equity/ assets	Probability NPV>0
Baseline		$896,801	0.0372	$455,888	0.945	0.78
Scenario 1	0	886,062	0.0361	450,429	0.945	0.78
Scenario 2	−5	781,577	0.0231	397,314	0.936	0.74
Scenario 3	−10	680,316	0.0091	345,838	0.929	0.58
Scenario 4	+5	998,247	0.0500	507,458	0.960	0.82

These starting values are required by the model, but will not affect the comparative analysis of using a TED.

Annual values for those costs which varied with level of production are presented in Table 2. In addition to these costs, dock space was set at an annual rental of $663. Fixed costs, those which are set at the beginning of the year and do not vary during the period under consideration, included only vessel insurance at $7,738. Other costs, such as depreciation and interest, were calculated by FLEETSIM.

By simulating the model for the nine year period, 1978-86, the ending financial position for the vessel was obtained. The vessel ends the 9 years with $122,469 in cash on hand and vessel assets worth $211,692, giving total asset value of $334,161. The only liability associated with the vessel was an intermediate-term debt of $17,155. Net present value for 9 years was $54,739. Internal rate of return was 8 percent.

Baseline Simulation

The baseline simulation was set up to simulate what would occur to the Gulf vessel during 1987-97. This was accomplished without considering the impact of TED regulations and results were later used to compare against those analyses where the TED policy was simulated. The baseline simulation was run for 50 different iterations which allowed average values to be generated for the statistics of interest.

The vessel, purchased in 1978 had a market value in 1987 of $211,692 and a replacement value was $400,000. Average ending net worth in year 10 for baseline simulation was $898,801 (Table 3). Although the value for average internal rate of return is low (3.72 percent), the use of a representative vessel in the simulation model contributed to this low value. The practice by many Gulf shrimpers of spreading the cost of running a vessel across many different operations, allows the vessel to be run less efficiently and still remain solvent; hence, a low internal rate of return for the vessel. Many vessel operators, however, are very efficient and generated much higher rates of return.

Average present value of ending net worth was $455,888 and average equity to asset ratio was 0.945, indicating the operator had a low debt level. The baseline simulation model had a 78 percent chance of generating a net present value greater than zero (with a discount rate of 7 percent).

Simulation with TED

Four different simulations were run to examine impacts of TED regulations on a typical Gulf vessel. Again, 50 iterations of each simulation allowed average values for the statistics of interest to be generated. These different scenarios were run assuming no impact on shrimp catch (Scenario 1), a 5 percent decrease in catch (Scenario 2), a 10 percent decrease in catch (Scenario 3), and finally a 5 percent increase in catch (Scenario 4). These results were as expected in that all economic indicators declined for negative impacts on shrimp production and increased for the positive impact on shrimp production (Table 3).

The next step in the analysis of the simulation results was to determine if the decrease or increase in the economic indicators was a significant change from the baseline simulation. This was accomplished by a statistical comparison of the means. The hypothesis tested was

$$H_0: \mu^1 - \mu^2 = 0,$$

with an alternative hypothesis of

$$H_1: \mu^1 - \mu^2 \neq 0.$$

The test statistic used

$$z = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu^1 - \mu^2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

which is an approximation of the Student t statistic, and can be used when sample sizes are sufficiently large (DeGroot, 1975). The sample sizes, n_1 and n_2, are equal to 50. This test statistic allows determination of significant differences from the baseline results but does not allow any comparisons to be made across all simulations. Since the primary purpose of this analysis was to determine if use of the TED resulted in a change in the economic well-being of the vessel, it was felt this test statistic would be sufficient.

The computed z-values for the various economic indicators are presented in Table 4. Each row examines the computed z-value for a TED scenario against the baseline scenario. Those test statistics which were significant at the 95 percent level are marked as footnote 2. It is apparent that all of the TED Scenarios where there is a change in the level of catch will cause a significant change in both Ending Net Worth in Year 10 as well as Present Value of Ending Net Worth. This is important because it indicates that even the discounted Net Worth is significantly different. However, Internal Rate

of Return (IRR) is not significantly different from the baseline until Scenario 3. In Scenario 2, where the impact on the shrimp catch is a loss of 5 percent, the calculated z-value is significant at the 80 percent level. There is no significant difference in the values for the Equity/Asset ratio between the baseline and any of the TED scenarios.

What this suggests is that the impact of the TED is significant if the vessel owner is primarily interested in vessel earnings. However, if alternative enterprises are to be considered then there is no appreciable difference in the rate of return associated with the decision to operate a shrimp boat or an alternative enterprise until the impact upon the shrimp catch is very large. It is also notable that the impact upon shrimp catch and therefore earnings, does not result in significant increases in debt levels in the TED scenarios. Because of the way the FLEETSIM model generates Probability of Net Present Value greater than Zero, it was not possible to use the above test to determine significant differences from the Baseline scenario.

Table 4.—Calculated z-values for output variables used in determining if TED scenario values are significantly different from baseline values.

Simulation	Percent impact on shrimp production	Ending net worth	Internal rate of return	PV of ending net worth	Equity/ assets
Scenario 1	0	1.517[1]	0.100	0.48	0.01
Scenario 2	−5	19.433[2]	1.365[1]	6.146[2]	0.281
Scenario 3	−10	18.289[2]	2.797[2]	12.168[2]	0.774
Scenario 4	+5	−15.155[2]	−1.18	−4.792[2]	0.645

[1]Indicates difference is significant at the 20 percent level.
[2]Indicates difference is significant at the 5 percent level.

Summary, Discussion, and Conclusion

This analysis is an intermediate analysis of the impact of the TED regulations. It does not explicitly consider the interactive aspects of the shrimp fishery both among vessels and between vessel catch and the remaining shrimp stock. This analysis is based on the resultant impact on the catch of a representative vessel in the Texas shrimp fishery given all interactive effects.

Four scenarios were analyzed for the effect of the TED on shrimp production. These were, no change, a 5 percent decrease, a 10 percent decrease and a 5 percent increase. The results were as expected in that all economic indicators declined for negative impacts on shrimp production and increased for the positive impact on shrimp production. A statistical analysis of the economic indicators pointed out that in Scenario 2 and 4, both of which represented a 5 percent impact upon shrimp catch, Ending Net Worth and Present Value of Ending Net Worth were significantly different from the baseline at a 5 percent level. Only in Scenario 3 (10 percent decline in catch) were Ending Net Worth in Year 10, IRR, and Present Value of Ending Net Worth all significantly different from the Baseline Scenario at a 5 percent level. Research to date, however, indicates that there are TED's, specifically the Georgia TED, which have experimental results consistently better than a 10 percent shrimp loss. In fact, the Georgia TED (or Georgia Jumper) has increased shrimp retention in all experiments reported here. If there is no effect upon shrimp landings as a result of pulling the TED, the only economic effect will be the cost of purchasing and maintaining the TED. These costs will have only a very minor impact on the shrimp industry.

It is important to note that no research has been undertaken on other impacts a TED may have on shrimping operations. For example, in addition to the impact which by-catch reduction may have on shrimp catch, the TED may also impact quality, onboard safety, and onboard handling of gear and shrimp fleet catches when all vessels are pulling a TED. None of these potentially significant impacts have been studied here or elsewhere.

As discussed, no conclusive statements could be made about the impact of the TED upon shrimp retention using the existing data. A first step in the analysis of the impact of TED regulations on the shrimp industry should be to analyze the combined effects of shrimp gain or loss by an individual vessel with biomass changes when all vessels in the industry use a TED and the individual vessel impacts from reduced by-catch. These combined effects entail looking at the impacts, in the limit, of shrimp gain or loss when tows are successively applied to a fixed biomass of shrimp over time. If the combined effect leads to shrimp loss to all vessels, then further statistically valid side-by-side tests of a TED or TED's on shrimp retention need to be done. The other issues of shrimp quality, safety and deck handling procedures could possibly be included in these further tests. However, if there is no significant shrimp loss to all vessels when considering the above combined effects, then further expensive side-by-side retention tests of TED's is not warranted.

Acknowledgment

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The By-catch From the Artisanal Shrimp Trawl Fishery, Gulf of Paria, Trinidad

VISHWANIE MAHARAJ and CONRAD RECKSIEK

ABSTRACT—Samples of shrimp trawl catches were collected from a commercial artisanal vessel fishing inside the 6-fm isobath in the Gulf of Paria, Trinidad. From August 1986 to May 1987, 34 late evening-early morning trawl trips were made and 97 hauls were sampled.

Annual ratio estimates were 9 (SD 1.3) finfish:shrimp and 14.7 (SD 2.0) by-catch: shrimp, with the highest ratios observed August through December and the lowest from late January through May, the dry season. Extrapolation of ratios, using shrimp catch statistics, indicates that for 1986, 974,000 kg of finfish and 620,000 kg of crabs, Callinectes *spp., were caught incidentally by artisanal shrimp trawlers fishing in the Gulf of Paria. Of this total incidental catch (1,594,000 kg), about 1,500,000 kg were discarded (94 percent).*

Four penaeid shrimp species are targeted: Penaeus schmitti, P. notialis, P. subtilis, *and* Xiphopenaeus kroyeri. Callinectes *spp. were caught in large quantities from August to mid-January. Small (4-15 cm) pelagic and demersal species of little commercial importance dominated the finfish by-catch:* Harengula *spp.*, Cetengraulis edentulus, Chloroscombrus chrysurus, Eucinostomous *spp.*, Diapterus rhombeus, *and* Cyclopsetta *spp. Altogether, the monthly percentage of the species ranged from 70 to 85 percent of the total finfish by-catch.*

Introduction

The continental shelf of northeastern South America is a highly productive fishing zone extending from east Venezuela to east of the Amazon River (Naidu and Boerema, 1972). The annual shrimp landings range from 15,000,000 to 20,000,000 kg (Villegas and Dragovich, 1984). However, an estimated yearly average of 200,000,000 kg of demersal finfish by-catch is thought to be discarded in this region (Jones and Villegas, 1980). For the western central Atlantic region, Klima (1976), concluded that the shrimp fisheries discarded approximately 1,000,000,000 kg of finfish. For most penaeid shrimp fisheries, this by-catch is the main component of trawl catches at 75-95 percent of the total weight (Alsopp, 1982; Griffiths and Simpson, 1972).

Finfish weight to shrimp weight ratios have been used to estimate quantities of by-catch. However, most reported ratios are calculated for the nonartisanal fishery. Finfish:shrimp ratios vary widely from area to area even in the same region. Slavin (1982) reported estimates of 19 for the north central Gulf of Mexico and 40 for the northeast Gulf of Mexico. In the South Carolina offshore shrimp fishery, Keiser (1976) found the finfish:shrimp ratio to be highly variable (3-136), with a definite seasonal trend. Furnell, (1982) estimated a ratio of 13 inside the 10-fm isobath off Guyana and observed that this ratio decreased with increasing depth. Other work in this region indicates values of 4 for the offshore fishery in Guyana (de Mesquite, 1982), 15 for the northern coast of Venezuela, and 10 for Brazil (Griffiths and Simpson, 1972). Watts and Pellegrin (1982) estimated finfish: shrimp ratios in Texas, and reported variation between years (12.94 in 1980 and 2.55 in 1981), attributed to the Texas closure in 1981. Dragovich and Villegas (1983) reported ratios ranging from 2 to 130 (average 19.5) for the artisanal trawl fishery operating along the northern coast of Brazil.

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In Trinidad, the artisanal trawlers fish within the nearshore region (mainly inside the 5-fm isobath) of the Gulf of Paria. Four penaeid shrimp species are the main target of this artisanal trawl fishery: *Penaeus schmitti*, *P. subtilis*, *P. notialis*, and *Xiphopenaeus kroyeri*.

Commercial landing statistics for Trinidad and Tobago are collected by the Fisheries Division, Ministry of Food Production, and accordingly in 1986 the artisanal trawl fishery was responsible for 30 percent (108,000 kg) of the total shrimp catch (Fisheries Division, Trinidad and Tobago, 1986). This study was formulated to determine by-catch:shrimp weight ratios to estimate the magnitude of the incidental catch, and to describe species composition and seasonality of trawl catches for the artisanal trawl fishery in the Gulf of Paria.

Materials and Methods

Study Area

This study was based on the local artisanal shrimp trawl fishery operating from Orange Valley in the Gulf of Paria, Trinidad (Fig. 1), or, more specifically, the Caroni platform in the depth range 0-6 fm. This Gulf is shallow with a mean depth of 15 fm, flat bottomed, and gently sloping, particularly along the coast (Gines, 1972). Composition of the bottom is mainly mud and silty-mud brought in by the Orinoco River and its tributaries (VanAndel and Sachs, 1964).

The Gulf of Paria has been described as a relatively calm, slightly stratified, semi-enclosed estuarine zone, where outflows from the Orinoco and other rivers mix with the water from the open ocean (Gines, 1972). Seasonal variability in the

surface salinity is tied to the Guyana current and Orinoco River (VanAndel and Sachs, 1964). During the wet season (June-December), surface salinities can be low (10-20‰), while in the dry season (January-late May) salinities may be as high as 35‰ (Kenny and Bacon, 1981).

The coastal zone in the Gulf of Paria is considered to be heavily polluted due to the highly populated areas nearby and industrial development[1].

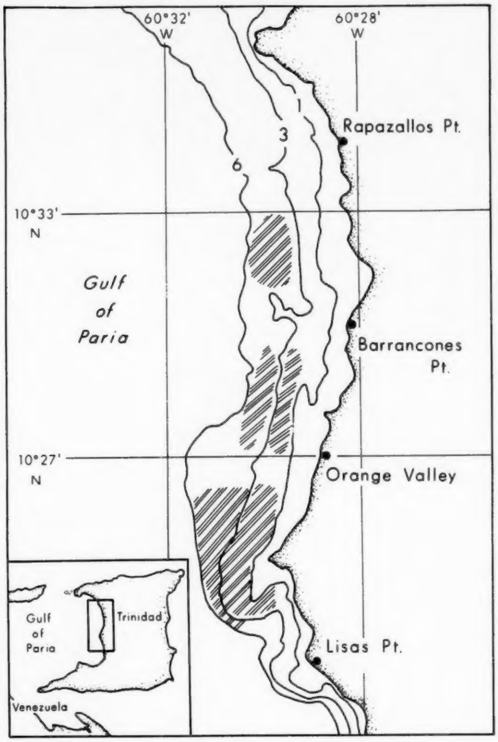


Figure 1.—Location of 97 trawl catches (hatched areas) by an artisanal trawler, August 1986 through May 1987, Gulf of Paria, Trinidad and Tobago.

The Commercial Fishery and Catch Statistics

The local artisanal trawl fleets fish within the 6-fm isobath in the Gulf of Paria close to their home ports, where they usually land most of their catch (Maharaj, 1989). Commercial statistics are collected on a daily basis by the Fisheries Division, Ministry of Food Production. Shrimp landings were extracted from these records for 1986 from the key sites Orange Valley, San-Fernando, and Otaheite in the Gulf of Paria (Maharaj, 1989). Also, members of the fishing community were interviewed informally during the course of this study.

Vessel, Gear, and Operation

The commercial vessel used in this study was an artisanal trawl vessel operating out of Orange Valley. This vessel was 9.8 m in length, wooden, and powered by an inboard diesel engine. There were no other mechanical aids on the vessel, nor were there any electronic devices. The crew consisted of two individuals: The captain and a deck hand.

A single four-seamed trawlnet was used with head rope length of 10 m, and codend mesh size of 3.8 cm. The ground rope, 14 m long, was weighted using lead pieces of 7-13 cm. Paired wooden rectangular doors (1.2 m × 0.5 m) were attached to this net.

The entire operation of setting and hauling in the trawl gear was done manually. Initially the cod end was set overboard from the stern; then the rest of the net was let out as the vessel moved forward. Finally, the otter doors were thrown overboard, and the time at this point was recorded as the start of the tow. The ratio of warp to depth was usually between 2:1 and 3:1 (according to the vessel's captain). Each warp was made fast to the fishing vessel.

After the completion of each haul, the net was brought aboard the vessel, the cod end untied, and the catch sequentially emptied into a number of bins (each bin held about 25 l). During the following haul, this catch was sorted by the crew. Shrimp and some finfishes were kept and the rest of the catch was discarded at sea.

The start and end of each haul were recorded as the time when the trawl doors were thrown overboard, and retrieved aboard the vessel, respectively. Tow duration varied from 1 to 3 hours depending on the area, depth, time of year, and other conditions. Also, the number of hauls per trip (per day's fishing) was dependent on these and other factors.

Sampling Method

It was decided that samples would be taken from a "typical" artisanal vessel operating under "normal" commercial conditions. Trawl catches were sampled at sea from this vessel which operated out of Orange Valley. The senior author was on board to collect weekly samples from 8 August 1986 to 26 January 1987 and bimonthly from 6 February 1987 to 22 May 1987.

Prior to the study, it was decided to stratify the sampling period (August 1986 to May 1987) into weekly intervals (each week began on Monday and ended on Sunday). Weekly stratification was chosen to capture the short-term fluctuations reported in trawl catches (Bazigos, 1974). One sample day per week was then

[1]Point Lisas environmental project VII. Fisheries. Institute of Marine Affairs report submitted to Point Lisas Industrial Port Development Corporation, May 1982, 25 p.

chosen randomly using a Lotus 123[2] function (@rand), which generated random numbers between 1 and 7.

Aboard the vessel the following data were recorded for each haul: Tow duration, fishing area, depth, number of bins filled, and approximate weight (to the nearest kilogram) of finfishes, shrimp, and crabs retained by the captain for market.

On each sample day, all trawl hauls were sampled by choosing one of the bins into which the catch was placed. The bin was chosen haphazardly and considered representative of that particular haul. Samples were kept on ice for later processing (Maharaj, 1989). Catch samples were sorted and classified to the lowest taxon possible. Total weight and number of each taxon were recorded.

Data Analysis

Estimation of Catch Rates From the Sample Data

Total weight per haul and total numbers per haul were calculated by multiplying the number of filled bins per haul by the weight and numbers in the sample, respectively. Catch rates expressed as weight per unit time (kg/hour) and numbers per unit time (no./hour), were determined from the catch data and the haul duration. The following order statistics were used to summarize these results: Median (M), lower fourth (L_f), and upper fourth (U_f).

Ratio Estimators

Two sets of ratios were calculated for each haul sampled: Finfish weight to shrimp weight (finfish:shrimp), and total by-catch weight (weight of finfish and crabs) to shrimp weight (by-catch: shrimp).

In an effort to reduce the bias of ratio estimators, the Jacknife method, modified according to Tukey (Rey, 1983), was used to calculate monthly ratios and variances:

$$R_o = \sum_{i=1}^{n} F_i \div \sum_{i=1}^{n} S_i,$$

$$\bar{R}_i = (\sum_{i=1}^{n} F_i) - F_i \div (\sum_{i=1}^{n} S_i) - S_i,$$

$$R_i = nR_o - (n-1)\,\bar{R}_i,$$

$$R_m = \sum_{i=1}^{n} (R_i) \div n,$$

$$Var(R_m) = \frac{\sum_{i=1}^{n} (R_i - R_o)^2}{n(n-1)},$$

where:

R_o = monthly ratio,
F_i = finfish weight in the ith haul,
S_i = shrimp weight in the ith haul,
n = number of hauls sampled per month,
R_i = Jacknife pseudo value, and
R_m = Jacknife ratio estimate.

By-catch Estimates for The Artisanal Fishery

Jacknife monthly ratio estimates were used together with the commercial landing statistics, i.e. the shrimp landings (for 1986), to estimate the total incidental by-catch for the artisanal fishery (B):

$$B = R_m \times S,$$

$$Var(B) = Var(R_m) \times S^2$$

$$B_c = B_t - B_f$$

$$Var(B_c) = \frac{\sum_{i-1}^{n} (B_c - \bar{B}_c)^2}{(n-1)}$$

where:

B = by-catch estimate,
S = shrimp landings 1986,
B_t = total by-catch,
B_c = crab by-catch,
B_f = finfish by-catch, and
$\bar{B}_c$ = annual average crab by-catch.

Monthly by-catch estimates (total by-catch and finfish by-catch) were calculated for all three landing sites in the Gulf of Paria. The crab by-catch was computed as the difference between the total by-catch and finfish by-catch, and its annual variance was calculated as indicated above. Since no data were collected for June and July 1987, mean ratios for May 1987 and August 1986 were used as ratio estimates for June and July, respectively.

Mean annual ratios were estimated from data collected during the 10-month sampling period, using the equations listed above, with the exception that n = 97 and R_m is the mean annual ratio. Each of the annual by-catch quantities was then calculated as the product of these ratios and the annual shrimp landings for 1986.

Discards from the Artisanal Fishery

In this artisanal trawl fishery, not all of the by-catch is discarded at sea. Some of this by-catch is marketed at landing sites, and these quantities are recorded by the Fisheries Division. From these records were obtained annual estimates of by-catch sold by this artisanal fishery. Discards were then calculated as the difference between the estimates of total by-catch and these commercial data.

Results

During this 10-month study, 97 hauls were sampled from 33 trawl trips (each trawl trip = 1 day's fishing). The entire artisanal fleet made over 5,000 trips during 1986 (Table 1). The sample hauls represented 220 hours of trawling time. From the fishing pattern of the vessel used in this study, it was concluded that artisanal vessels trawl in depths between 1.5 and 2.5 fm from August until mid-January, and after this period they move further offshore into depths exceeding 3 fm (Maharaj, 1989).

Catch Components and Abundance

The total (shrimp, finfish, and crab) catch per unit effort (CPUE; expressed as kg/hour) was highest (usually >100 kg/hour) during August. Thereafter, this CPUE steadily declined throughout the remainder of the wet season (Fig. 2). This trend of declining catch rates continued through the dry season where CPUE did not exceed 50 kg/hour, with median values between 10 and 20 kg/hour (Fig.

[2]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 1.—Disposition of sampling effort with total artisanal fleet effort (number of trips) for 1986. Jacknife monthly ratios based on 97 trawl catches by an artisanal trawler, August 1986 through May 1987, Gulf of Paria, Trinidad and Tobago. Commercial shrimp landings for the artisanal fishery, 1986, provided by the Fisheries Division, Ministry of Food Production, Trinidad and Tobago. Estimates of crab, finfish, and total by-catch, together with their standard deviations, calculated from the ratios and commercial data.

Item	Jan.	Feb.	Mar.	Apr.	May	June[1]	July[1]	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Number of trips													Total
Fleet effort	638	510	550	598	586	423	404	442	347	350	367	264	5,479
Sampling effort	5	3	2	2	2			3	3	5	4	4	33
Estimated ratios													Mean
Finfish:shrimp	7.06	2.22	2.41	3.26	5.21	5.21	27.86	27.86	6.17	7.90	58.34	23.04	8.99
S. D.	1.86	0.40	1.15	0.38	1.12	1.12	22.25	22.25	1.45	2.56	22.29	16.84	1.25
By-catch:shrimp	8.75	3.33	2.72	4.46	7.22	7.22	53.47	53.47	13.74	16.14	87.32	35.03	14.71
S. D.	2.30	0.60	1.15	0.72	2.21	2.21	25.91	25.91	3.32	5.88	31.09	25.66	2.03
Weight (kg)													Total
Shrimp landings, 1986	11,844	10,951	14,797	15,775	11,679	7,973	6,588	9,181	5,733	5,073	4,577	4,186	108,357
Crab by-catch	20,058	12,133	4,549	18,930	23,475	16,027	168,718	235,117	43,402	41,778	132,623	50,186	619,804
Finfish by-catch	83,575	24,334	35,700	51,426	60,848	41,541	183,540	255,774	35,375	40,099	267,027	96,438	974,132
S. D.	22,030	4,380	17,017	5,994	13,081	8,930	146,582	204,270	8,313	12,987	102,018	70,487	135,447
Total by-catch	103,634	36,467	40,249	70,355	84,323	57,568	352,258	490,891	78,777	81,877	399,650	146,624	1,593,935
S. D.	27,241	6,571	17,017	11,358	25,811	17,621	170,694	237,871	19,035	29,829	142,294	107,405	219,965

[1] Ratios used for June and July were ratios calculated from May and August data, respectively.

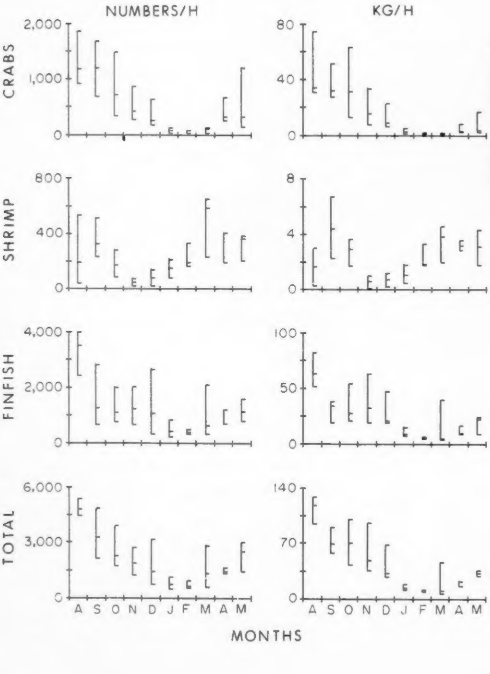


Figure 2.—Median monthly catch rates bounded by lower and upper fourths, based on the 97 trawl catches by an artisanal trawler, August 1986 through May 1987, Gulf of Paria, Trinidad and Tobago.

2). The annual median total catch rate observed, from these 97 hauls sampled, was 34 kg/hour (Maharaj, 1989).

Distinct seasonality in abundance was depicted by the crab catch rate data (Fig. 2). Catch rates were highest in the wet season and decreased markedly from November (median of 31 kg/hour in October to 16 kg/hour in November). Thereafter the catch rates fell off further, remaining at low levels (<10 kg/hour) in the dry season.

Catch rates of finfishes fluctuated throughout the year, with a less pronounced seasonal trend than described above. The lowest catch rates were observed during the dry season (median of <10 kg/hour).

In contrast to the crab and finfish components, the highest shrimp catch rates were observed from mid-September to mid-October in the wet season and from January to May (Fig. 2). Catch rates were consistently higher during the period from March to May (median of 3-4 kg/hour) and lowest during November and December.

Ratio and By-catch Estimates

Annual Jacknife ratio estimates were 9.00 (SD 1.25) finfish:shrimp and 14.70 (SD 2.00) by-catch:shrimp (Table 1). The distribution of monthly ratio estimates could also be linked to seasonality, with the highest ratios observed during the wet season. The lowest ratios, <10, were frequent from late January to May, in the dry season (Fig. 3).

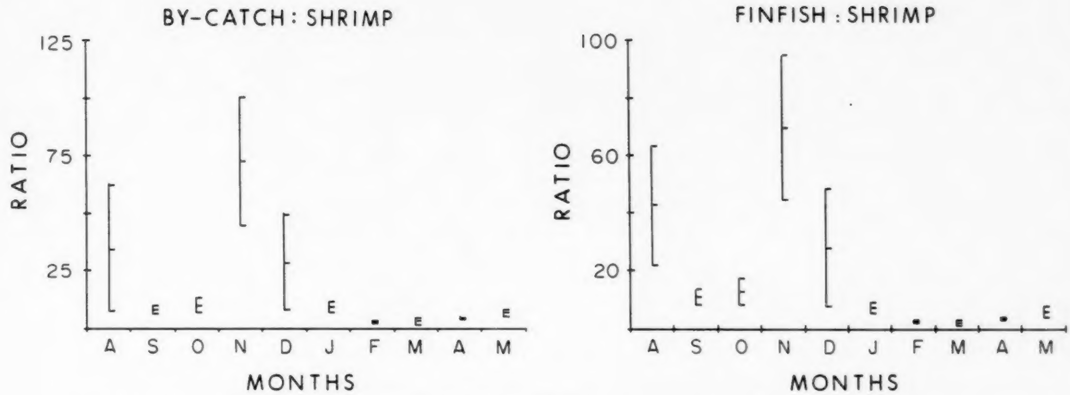


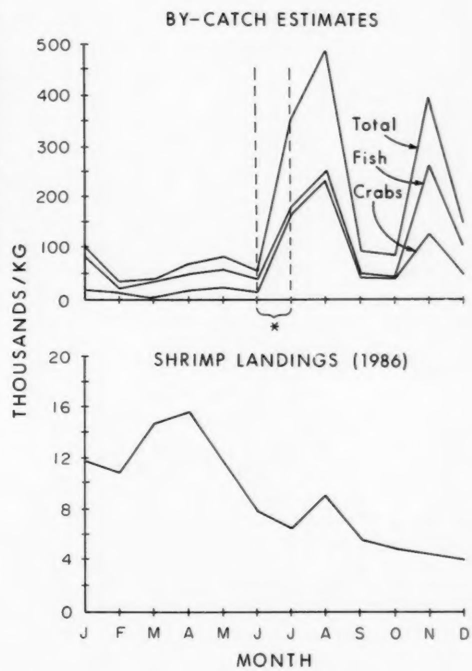
Figure 3.—Jacknife monthly by-catch ratios with one standard deviation about the mean, based on 97 trawl catches by an artisanal trawler, August 1986 through May 1987, Gulf of Paria, Trinidad and Tobago.

Table 2.—Estimated discards in the artisanal trawl fishery, 1986.

Item	Amt./%	Reference
By-catch landed	93,548 kg	Trawl by-catch sold in 1986, taken from the commercial shrimp landings for the artisanal trawl fishery, 1986[1].
Estimated by-catch	1,593,935 kg	Estimated total discards taken from Table 1.
By-catch landed	5.87%	Percentage of total estimated by-catch sold.
By-catch discarded	94.13%	Percentage of total estimated by-catch discarded.

[1]Fish. Div., Minist. Food Prod., 1986.

Figure 4.—By-catch estimates for the artisanal trawl fishery based upon 97 trawl catches by an artisanal trawler, August 1986 through May 1987, Gulf of Paria, and commercial shrimp landings for the artisanal trawl fishery, 1986, provided by the Fisheries Division, Ministry of Food Production, Trinidad and Tobago. The by-catch estimates for June and July (*) were calculated using ratios determined for May and August, respectively.



The total annual by-catch estimate for the Gulf of Paria artisanal trawl fishery in Trinidad was 1,594,000 kg (SD 220,000), composed of 974,000 kg (SD 135,000) finfish and 620,000 kg (SD 70,800) crabs (Table 1), for reported shrimp landings in 1986 of 108,000 kg (Table 1). The highest quantities of by-catch were harvested from July to December, corresponding to the period of the lowest shrimp landings (Fig. 4). About 6 percent (93,600 kg) of the total annual by-catch was probably sold, therefore more than 90 percent of this estimated by-catch was discarded at sea (Table 2).

Species Composition

Four penaeid shrimp species were found in these trawl catches. From this study it appears that *Penaeus schmitti* was mainly present from September to October. In contrast, *P. notialis* and *P. subtilis* dominated the trawl samples from January to May. *Xiphopenaeus kroyeri* only appeared sporadically in the catches from August to January. *Callinectes* spp. were caught in large quantities only during the wet season (Maharaj, 1989).

Subadults and juveniles of the following species dominated the finfish by-catch: *Harengula* spp., *Cetengraulis edentulus*, *Chloroscombrus chrysurus*, *Eucinostomous* spp., *Diapterus rhombeus*, and *Cyclopsetta* spp. These species altogether accounted for 70-85 percent of the finfish by-catch. It was clearly apparent that *Harengula* spp. and *Cetengraulis edentulus* were present in significant quantities only in the wet season. For the other finfish species mentioned above, catch rates fluctuated chaotically without any distinct seasonal trend (Maharaj, 1989).

Discussion

The annual weight ratio estimates of 14.7 (SD 2.00) by-catch:shrimp and 9.0 (SD 1.25) finfish:shrimp were comparable to other results from the western central Atlantic fishing region, which ranged from 10 to 20 inside the 10-fm isobath (Dragovich and Villegas, 1983; de Mesquite, 1982; Griffiths and Simpson, 1972). The annual estimates in this study did not reflect the wide variation in the data; the coefficient of variation (SD/ratio) was less than 15 percent for the annual estimates. However, during August, November, and December when the ratios were high (>30), the coefficient of variation ranged from 50 to 90 percent.

Throughout the dry season, an increase in shrimp catches and a simultaneous decrease in the crab and finfish components were apparently responsible for the low ratios estimated from January to May. In the wet season, the ratios were higher, except for September and October, which corresponded to the peak in abundance of *P. schmitti*, and hence the ratio estimates for these months were lower than those for August, November, and December.

These results indicate that the highest finfish catch rates occurred during August-December in the Gulf of Paria. Many explanations have been given for seasonal finfish catch variations. Lowe-McConnell (1962) found catches of trawled finfishes in Guiana to be highest during the rainy season when they move into shallower areas. Moore et al. (1970) linked high seasonal finfish abundance in an inshore area (1-10 fm in Louisiana) with recruitment from estuaries. Gunter (1938) associated this trend in Louisiana with seasonal breeding cycles, influx of recruits large enough to be caught in the trawl, or migration of old or young individuals from another locality.

Another factor which could be partly responsible for these abundance fluctuations is the change in depth of fishing. From January to May, fishing depth increased slightly (from 1-2 fm to >3 fm). Furnell (1982) reported that "Assessment of incidental catches of fish by trawlers operating in Guianese waters showed that the largest quantities of fish are caught in shallow waters (less than 15 fm), whereas the largest quantities of shrimp are caught in deeper waters (22-39 fm)."

The wide fluctuation in finfish catch rates observed here are likely typical of finfish assemblages captured by shrimp fleets. This is probably attributable to the nonrandom distribution of finfish populations (Keiser, 1976; Taylor, 1953). In this fishery we observed a tendency for fishermen to avoid areas where large quantities of by-catch were caught. The latter could explain the high variances of the large ratio estimates in August and November-December, when shrimp catches were poor.

The Jacknife method used to calculate the ratio estimates was an appropriate procedure since it not only reduces the bias in these ratio estimates, but it also assumes no particular data distribution (Rey, 1983). All data recorded were used to estimate the monthly and annual average ratios. Most authors exclude high ratios (>100) from their calculations (Keiser, 1976); however, we decided that to do so would lead to an underestimation of by-catch.

Our estimates were based on the assumption that, "on average," the vessel in this study was representative of the fleet at comparable times and area fished. Comparison of sampling effort and commercial fishing effort during 1986 is contained in Table 1. As mentioned, the artisanal trawl fleet fishes within the 6-fm isobath in the Gulf of Paria. The distribution of sampling effort by area for this study vessel is depicted in Figure 1. It is our belief that this area represents about 80 percent of that covered by the commercial fleet; our sampling vessel did not venture into the most southerly sections of the fleet's operational area.

Only 6 percent of the by-catch is marketed, unlike most artisanal trawl fisheries where most by-catch is retained (Saila, 1983). An estimated 1,500,400 kg of finfish and crabs are discarded annually from this artisanal trawl fishery. These discards may provide a large food source for the crab populations and account for the latter's abundance. It was observed during this study that discarded finfish were fed upon by sea birds. Possibly crabs (most of the crabs in the by-catch were returned to the sea alive) and other organisms may also be attracted to these discards (Saila, 1983). However, it is generally believed that most of the discards usually decompose and become remineralized into nitrogen and other nutrients (Cushing, 1981; Sheridan et al., 1984).

One of the important issues for Trinidad and Tobago is whether groundfish landings by the directed fisheries (demersal longlines and trawl) are adversely affected by shrimp trawling. If this were the case, then a host of management regimes, based on closed season/areas (Villegas and Dragovich, 1981; Caddy, 1982; Garcia, 1986) and/or gear restrictions/modifications (Siedel and Watson, 1978; Jones, 1976; Hickey and Rycroft, 1983; McVea and Watson, 1977), could be employed in an attempt to reduce the by-catch.

Acknowledgments

We acknowledge the Fisheries Division, Ministry of Food Production, Marine Exploitation, Forestry and the Environment, Trinidad and Tobago, whose resources made this study possible. We also want to thank C. Maharaj as well as members of the fishing community for their assistance during this project. This is contribution number 2541 of the Rhode Island Experiment Station.

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Construction and Operation of a Two-place Diver's Sled

IAN K. WORKMAN and JOHN W. WATSON

Introduction

Fisheries gear researchers have employed scuba diver-operated sleds to evaluate towed fishing systems since the early 1950's. One of the earliest sled designs was a converted Stokes litter in which two divers sat tandem with the forward diver operating the diving controls (Sand, 1956). The litter was relatively easy to maneuver and provided a comfortable platform for observing operational fishing gear. However, the use of underwater photographic equipment to document gear performance was difficult due to the limited mobility of the observer-cameraman.

A new two-place diver's sled, designed specifically for underwater cinematography, was introduced in the late 1950's (Hold, 1960). This sled allowed the divers to lie side-by-side which greatly reduced water resistance. The sled pilot occupied the port position, and the observer-cameraman, facing either forward or aft, occupied the starboard position. This design offered two advantages over the converted Stokes litter: 1) It was more maneuverable due to the location of its towing point and 2) it facilitated the use of underwater photographic equipment. Disadvantages of this steel sled were that it was heavy, subject to corrosion, and accessory flotation tanks were necessary for positive buoyancy.

The weight and corrosion problems were solved in the late 1960's by replacing the steel frame and wooden control surfaces with aluminum[1]. The lighter weight and reduced accessory flotation requirements made the aluminum two-place diver's sled more maneuverable than the steel sled. Because of its excellent handling and performance characteristics, it has become a standard piece of equipment for use in towed fishing gear evaluations by the Harvesting Systems Branch, National Marine Fisheries Service, Mississippi Laboratories, Pascagoula Facility.

In addition to fishing gear research, a number of other applications for diver operated sleds have evolved, including: Evaluation of towed instruments; biological, archeological, and geological surveys; and search and recovery operations. This report provides the information necessary to construct and operate a two-place diver's sled. It is not, however, intended to replace instruction or field training in sled operations.

Construction

Constructed entirely of aluminum, the two-place diver's sled has an overall length of 2.3 m (92¼ inches) and a width of 2.2 m (87¾ inches) (Fig. 1). Fully rigged, the sled's out-of-water weight is about 41 kg (90 pounds). Watertight welds and two attached side floats provide positive buoyancy.

Materials Required

1) 87 feet 6 inches of 1-inch internal diameter (ID) schedule 10 aluminum pipe
2) 1 foot 10 inches of 1⅜-inch ID schedule 10 aluminum pipe
3) Four 26½- by 15½-inch sheets of $\frac{3}{16}$-inch aluminum
4) Two 46- by 14-inch panels of #36 nylon webbing
5) One spool of #42 (or #60) nylon twine
6) One ¾-inch shackle
7) One ⅝-inch swivel
8) Two 14- by 6-inch plastic (or styrofoam) floats
9) 12 inches of 3.8-inch aluminum rod
10) Two 2-link sections of $\frac{3}{16}$-inch chain
11) Two $\frac{3}{16}$-inch lap links
12) Two $\frac{3}{16}$-inch shackles
13) Two #3 snap hooks
14) Diver depth gauge
15) Bicycle flag and staff

Sled Frame—Top Section

The top section of the sled frame is constructed from 1-inch ID aluminum pipe (Fig. 2). The two outside frame members measure 84 inches long and are connected at the after end by a 50-inch pipe section. Forward, they are connected by two 19-inch pipe sections and a central "Y" section. The "Y" section is made with two 23½-inch pipes which join with a central pipe measuring 64 inches long. The other end of the central pipe is attached to the middle of the 50-inch pipe. A 3-inch pipe is attached between the two "Y" members to later serve as an attachment point for a towing swivel.

Sled Frame—Bottom Runners

The bottom runners are made from two 110½-inch lengths of 1-inch ID alumi-

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[1]L. H. Ogren. 1983. National Marine Fisheries Service, SEFSC, 3500 Delwood Beach Drive, Panama City, FL 32407. Personal commun.

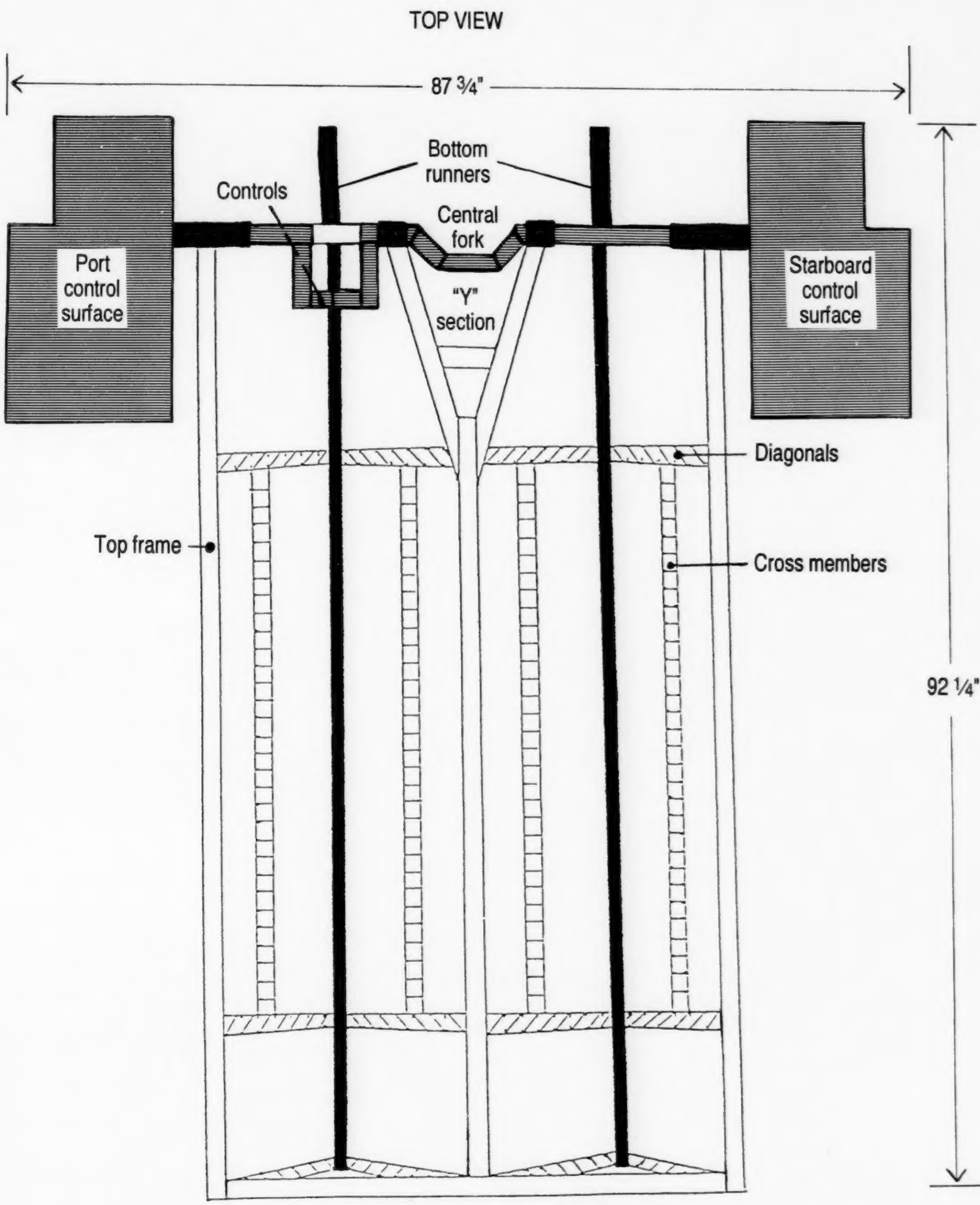

Figure 1.—The two-place diver's sled.

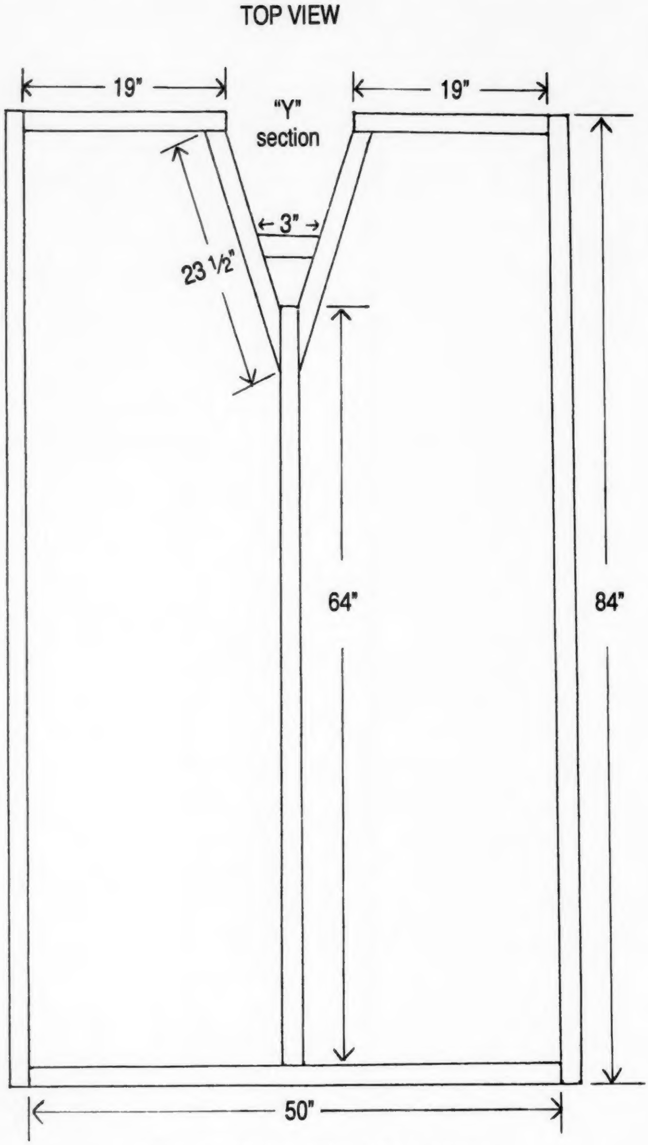

Figure 2.—The top section of the sled frame.

num pipe (Fig. 3). The leading end of each pipe is bent into a half circle with an inside diameter of 14½ inches. The runners are attached 9½ inches inward on the two 19-inch forward pipe sections of the top frame.

Sled Frame—Diagonal and Cross Members

There are 12 diagonal members (Fig. 4). Six outside diagonals attach between the runners and the outside top frame, and six inside diagonals are attached between the runners and the middle pipe of the top frame. The outside diagonals are 17 inches long, and the inside diagonals are 21 inches long. They are attached at three points along the sled frame. The first set of four (two outside and two inside diagonals) is attached to the after end of the sled. The next set is attached 17 inches inward, and the last set is attached 62¼ inches inward from the aft end of the sled. Four 45¼-inch cross members are attached between the forward and middle sets of diagonals. The outside cross members are attached 6½ inches down from the outside top section, and the inside cross members are attached 8¼ inches down from the middle pipe of the top section.

Control Surfaces

Two pieces of $\frac{3}{16}$-inch aluminum sheeting measuring 26½ inches × 14 inches are used to make the top and bottom of each control surface (Fig. 5). A section 9¾ inches long and 3¾ inches across is removed from each sheet. A 1-inch ID pipe is placed between the two sheets and aligned with the edge of the 3¾-inch cut. A 24¾-inch pipe is used for the port control surface, and a 39¼-inch pipe is used for the starboard control surface. The two sheets are welded to the pipe and bent equally top and bottom to join the two ends. Side pieces are then fitted between the top and bottom sections.

Controls

The guides, which allow the control rods to rotate freely, are made with 1⅜-inch pipe (Fig. 6). Two of the guides are 8 inches long, and two are 3 inches long. The 8-inch guides are attached with 3 inches of outside overhang to the forward port and starboard sides of the top sled frame. The 3-inch guides are attached with their inner edges even with the inside of the "Y" section. The 24¾-inch pipe, with the port control surface attached, is inserted through the 8-inch guide on the port side of the sled and attached to the port control handle assembly. The control handle assemblies (port and starboard) consist of a 4¼-inch top pipe, an

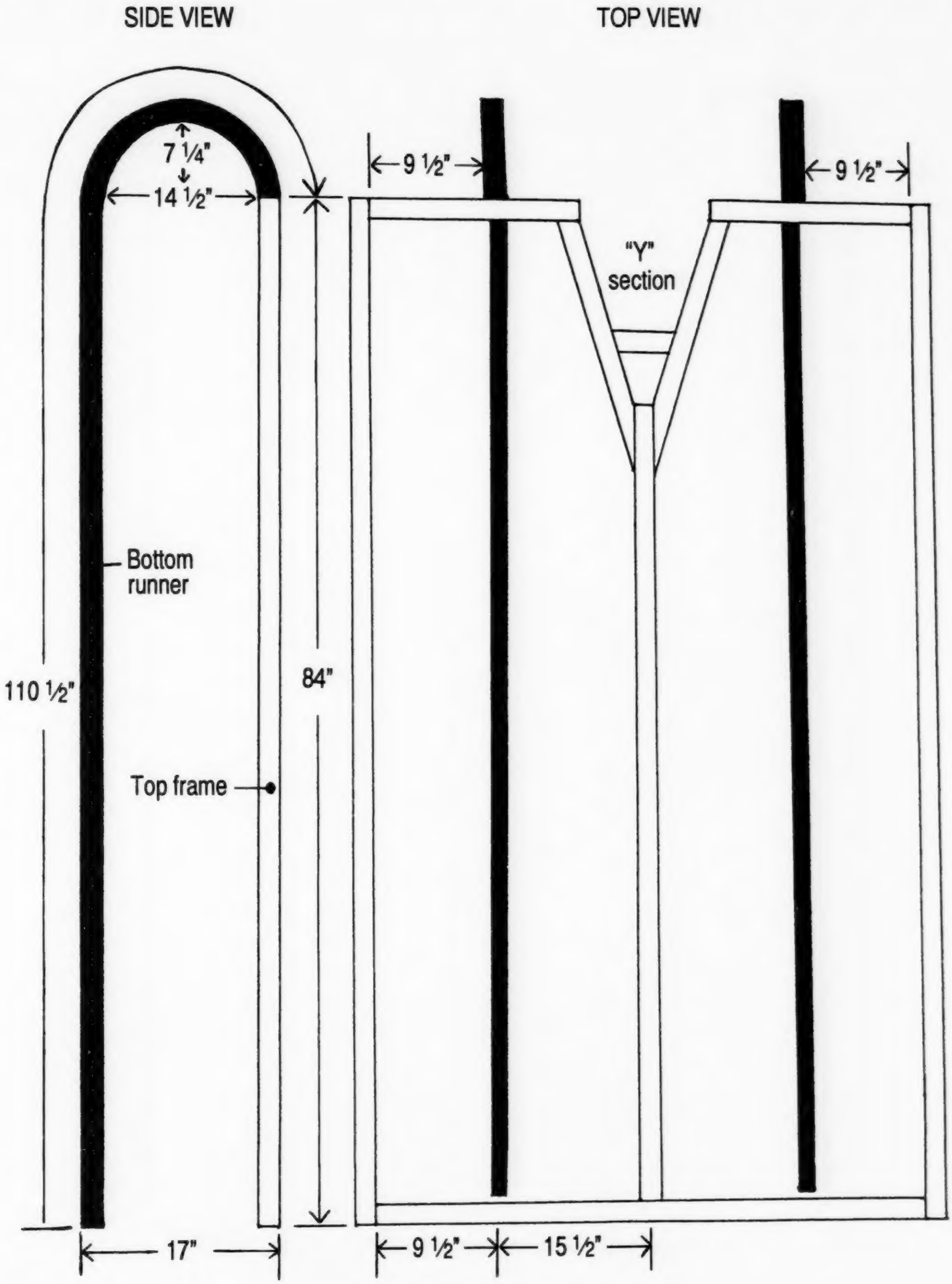

Figure 3.—The bottom runners of the sled frame.

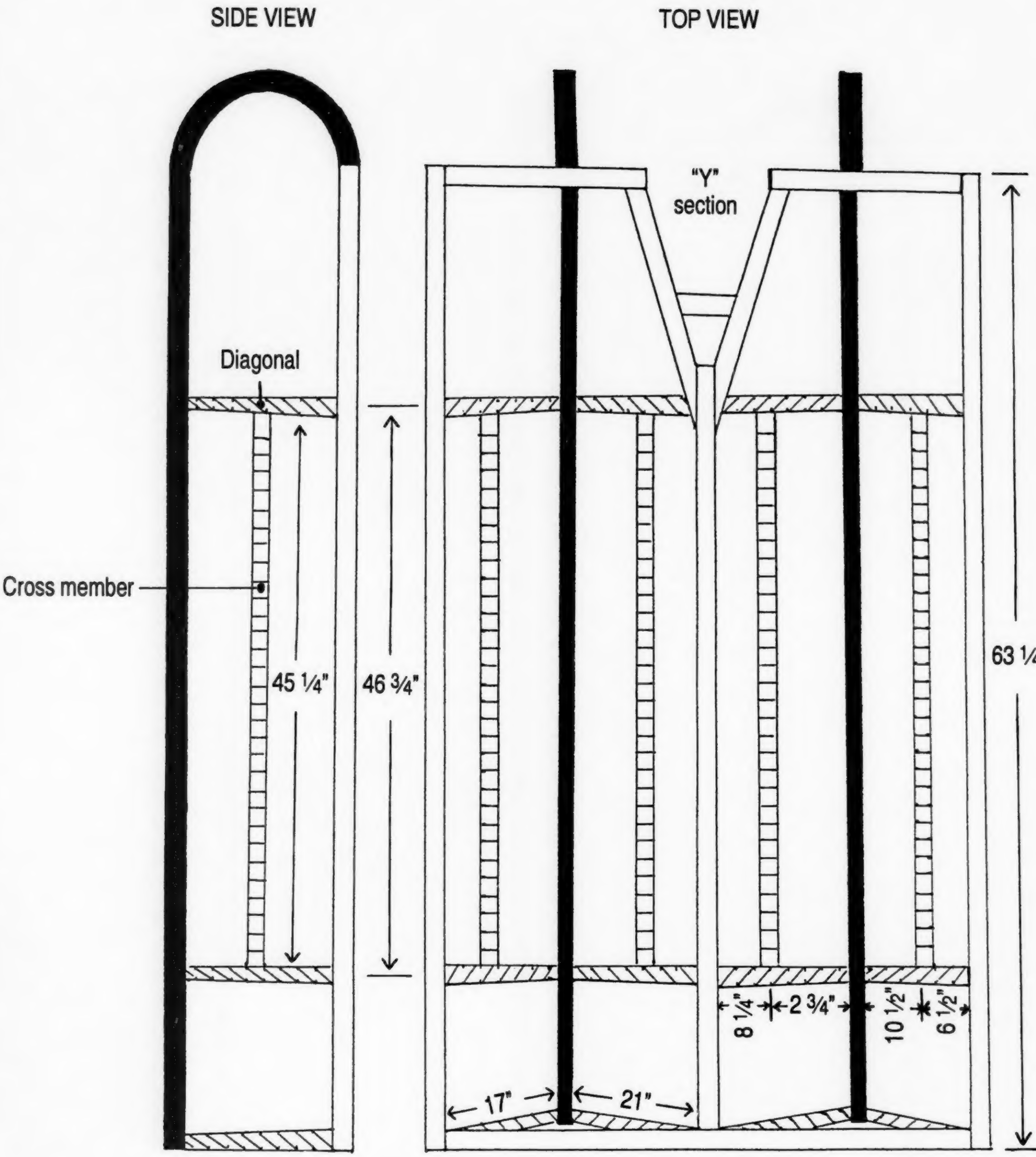

Figure 4.—Diagonals and cross-members of the sled frame.

8-inch down pipe and a 6-inch handle. The 39¼-inch pipe of the starboard control is inserted through the 8-inch and 3-inch guides and is attached to a central fork. The fork has 14¼-inch sides and a 6½-inch base. A 7-inch pipe is inserted into the port 3-inch guide to connect the fork and starboard control handle assembly.

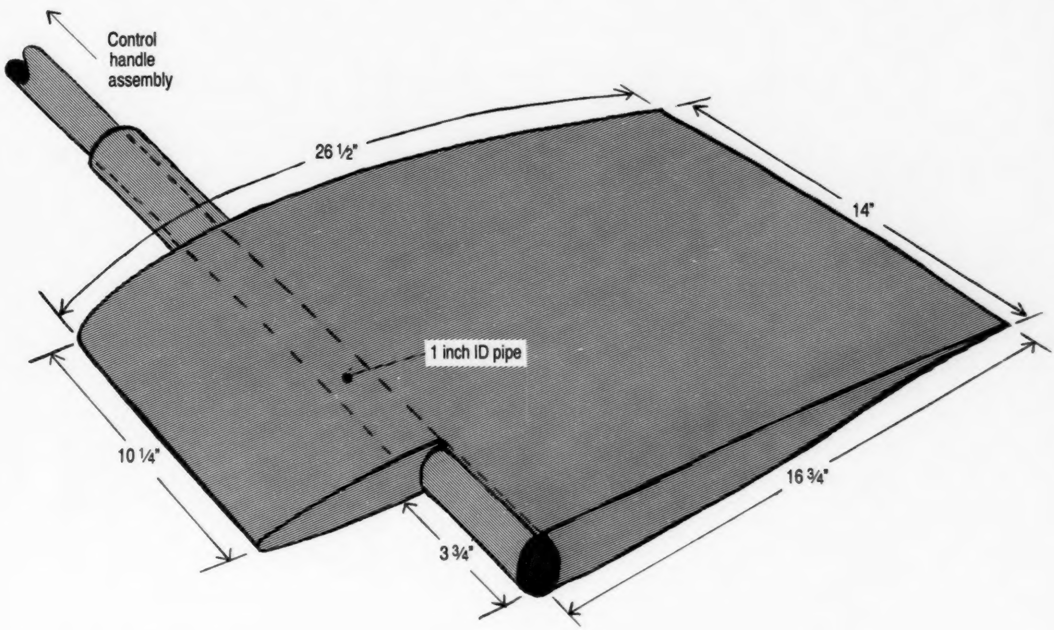

Figure 5.—Port control surface.

Accessories

Two nylon webbing panels, each measuring 46 × 14 inches, form belly pads for the divers. They are attached with nylon twine between the inside and outside cross members on the port and starboard sides. For increased support, 3/16- to 1/4-inch line can be woven through the front and back edges of the belly pad and attached between the cross members.

Two 6- × 14-inch floats are attached with line or webbing to the two outside forward diagonals between the top frame and outside cross members.

A 5/8-inch swivel is attached to the 3-inch pipe between the top frame "Y" section with a 3/4-inch shackle to provide a twist free attachment point for the tow line.

Sled control restraint (Fig. 7) keep the sled in an upright plane when towed at the surface without divers. They are constructed with three 4-inch pieces of 3/8-inch aluminum rod, each bent into U-shapes; two 2-link sections of 3/16-inch chain; two 3/16-inch lap links; two 3/16-inch shackles; and two #3 snap hooks. Two of the 4-inch U's are attached with one end to the down pipe and the other end to the handle on both control handle assemblies. The third 4-in U is attached just above the center of the curve (bottom end of U at center of curve) on the bottom runner control side of the sled. The 2-link sections of 3/16-inch chain are attached to the #3 snap hooks with the two 3/16-inch lap links. These two chain and hook assemblies are attached to the 4-inch U on the bottom runner with the two 3/16-inch shackles. The snap hooks are snapped into the two 4-inch U's on the control handle assemblies (one hook to each control) to hold the control surfaces in an ascent position (leading edge of control surfaces up).

A depth gauge, positioned so that it can be clearly viewed by the pilot, is mounted to the forward section of the top frame where the bottom runner attaches on the pilot's side. A bicycle flag staff, about 3 1/2 feet long, and a flag are attached to either outside aft end diagonal. When the sled is on the surface, the flag should protrude at least 2 feet above the water.

If divers are to be towed long distances at relatively high speeds, a "water shield" (underwater counterpart to a windshield) can be attached. The shield can be constructed from clear Lexan or Plexiglass in an aluminum frame. It is attached to the forward part of the top frame.

Operation

The sled's light weight and easy handling characteristics make it ideally suited for towing from almost any size vessel. The sleds we use have been towed from vessels as small as a 14-foot skiff powered by a 9 hp outboard motor, up to a 174-foot research vessel powered by two 800 hp

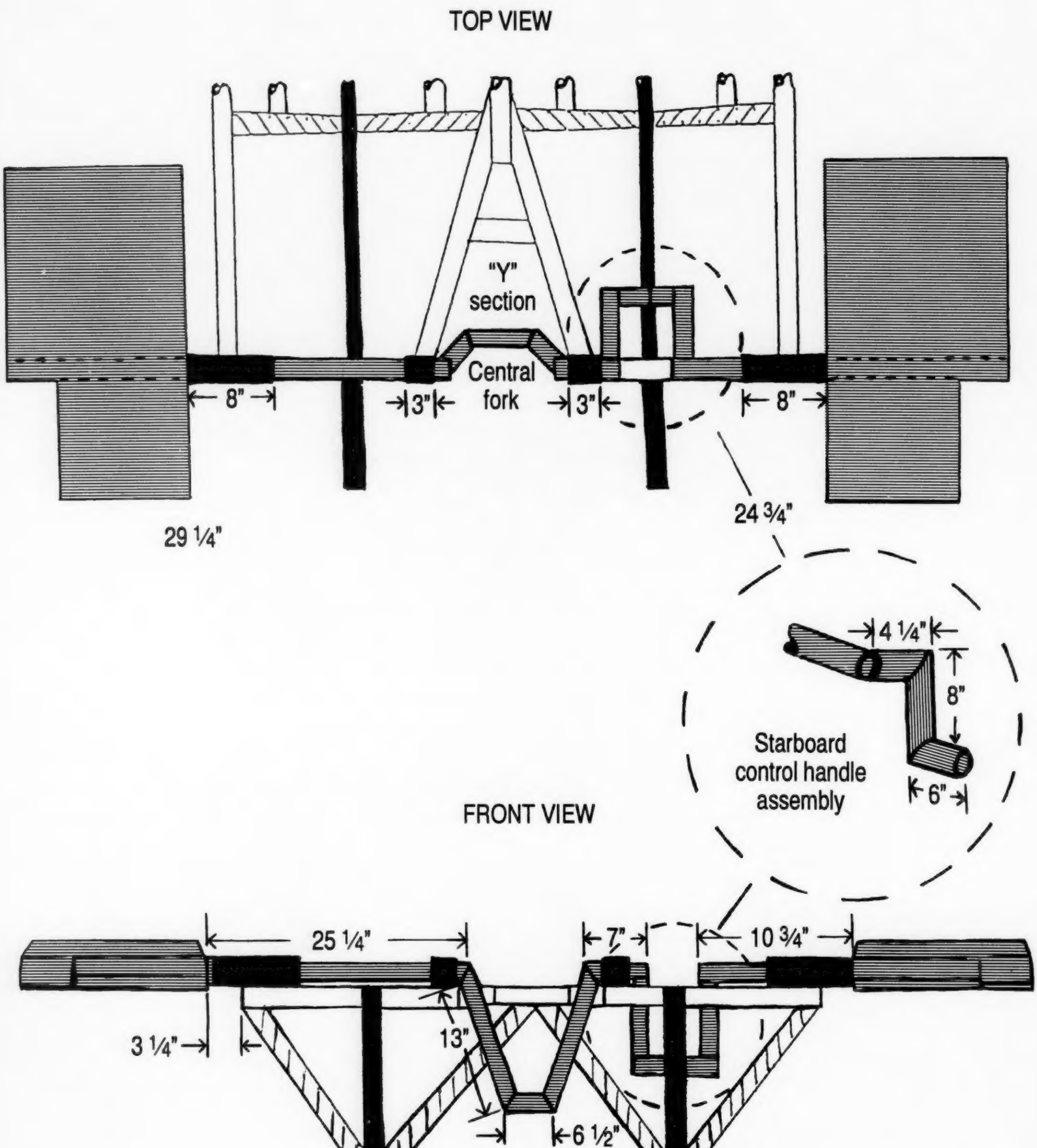

Figure 6.—Sled dive controls.

diesel engines. The only limiting factor is speed. Safe operating speed ranges from about 0.5 to 4 knots.

Selection of the size of the sled towline is dependent upon line type, towing speed, and the towing vessel's handling capabilities. For a nylon towline, the size ranges from ⅜ to ¾ inches. Warp (the amount of towline) depends on the depth

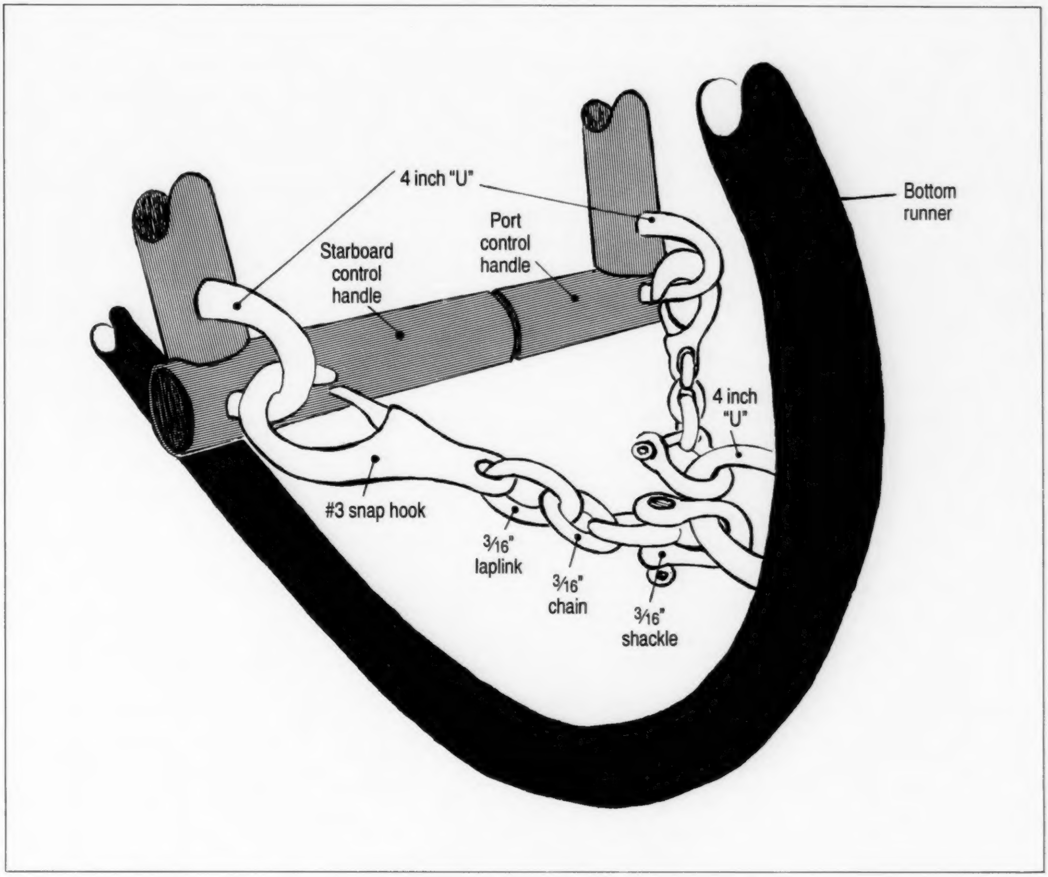

Figure 7.—Sled control restraints.

of operation. Optimal performance is achieved with a warp to water depth ratio of 5:1 or greater.

The sled can be boarded and disembarked while it is stationary in the water or under tow. Boarding a stationary sled is relatively easy. The sled pilot to port and observer to starboard slide on, either singly or together, from the sides or the stern, and assume a prone position. A third diver, when needed, would take a central position between the pilot and observer. As the sled is boarded it will sink, and care must be taken to avoid capsizing. Towing can begin when the divers are ready. Disembarking is accomplished when the sled comes to a stop at the surface. The divers simply slide off the sled and swim to the towing vessel or support boat.

Wickham and Watson (1976) describe a safe and effective method of boarding and disembarking a towed dive sled. The divers, transported in a support boat (separate from the towing vessel), are positioned well ahead of the sled and close to the downwind side of the sled towrope. When the divers are ready to enter the water, the support boat is turned away from the towrope, and the motor is taken out of gear.

Once the divers are in the water and clear of the propeller, the support boat is moved to a position slightly behind and downwind of the sled. The divers position themselves 20-30 feet apart on opposite sides of the towline. The pilot takes the lead position facing the sled's port side, grabs the passing control surface or sled frame, and trails back to a parallel position. The pilot then slides aboard the sled and assumes a prone position at the controls. The observer boards the sled in the same manner from the opposite side.

When the divers are positioned, the pilot releases the control restraints and assumes control of the sled. At the end of the dive, the sled is brought back to the

surface and the control restraints are reattached. The support boat is then signaled in to a parallel position close to the downwind side of the sled. On the pilot's signal, the support boat's motor is taken out of gear, and the divers kick free of the sled and swim to the support boat.

Piloting the Sled

The sled pilot must be experienced in the handling characteristics of the sled and familiar with the requirements of each diving operation. During a dive, the pilot must maintain open communications with the passenger(s) and be aware of any changes in depth. Depth changes without adequate time for the divers to equalize pressure in internal air spaces could result in barotrauma, air embolism, or other related problems. An accelerated ascent rate faster than 18.3 m/minute (60 feet/minute) following a long or deep dive could result in decompression sickness. The following are basic flight control instructions.

Descent

Both control handles are pulled back toward the pilot. The rate of descent is dependent upon towing speed and the distance the control handles are pulled back.

Ascent

Both controls are pushed forward away from the pilot. Ascent rate is dependent upon towing speed and the distance the control handles are pushed forward.

Level Flight

Once working depth is reached, the pilot places the control handles at their approximate midpoint. To maintain level flight, slight back and forth adjustments might be necessary.

Flying to Starboard

After submerging (descent), the pilot pulls the port control handle back and holds the starboard control at its midpoint or pushes it slightly forward. When the desired angle of attack is reached, the pilot pulls the starboard control back. Slight adjustments in the controls might be required to maintain the angle of attack. For side flight without depth change, the sled must be turned and held perpendicular to the bottom.

Flying to Port

Opposite of flying to starboard.

Barrel Roll

At times it may be necessary to completely roll the sled. To do this, the sled must be submerged to a depth (dependent upon speed) that it will not break the surface as it rolls. One control handle (port or starboard) is pulled all the way back while the other is pushed all the way forward.

Safety Notes

Safety should be stressed at all times in the use of a diving sled and in the overall operation of its towing vessel and support boat. Adequate diving instruction as outlined in the NOAA Diving Manual (Miller, 1979) should be obtained before receiving sled operation instructions, and all sled users should receive classroom and practical in the field instruction before attempting to use a diver's sled.

Communication is a primary safety factor in using a diver's sled. Although voice communication is possible with proper underwater communication equipment, it is not always practical, depending on the type of diving operations conducted. It is therefore most important that the sled pilot and observer(s) learn a simple set of hand signals (depicted in the NOAA Diving Manual) before attempting a sled dive. The center for communications is the pilot who has overall control of the dive. It is the pilot's responsibility to insure that all sled flight changes (e.g., descending, ascending, etc.) are communicated and clearly understood by the observer(s) before they are initiated. The observer can initiate communications with a light tap or squeeze on the pilot's arm.

All sled users should have a working knowledge of Boyle's Law and understand the possible problems involved with pressure-volume changes (e.g., barotrauma, air embolism, and other related problems). Particular attention should be paid to breathing rhythm. On descent and level flight, breathing should be regular. When ascending, the breathing rhythm should be modified to shortened inhalations followed by long exhalations to prevent lung over-pressurization.

Acknowledgments

We thank Chris Gledhill, Ren Lohoefener, Wilber Seidel, and Warren Stuntz for their suggestions and constructive criticism.

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Maturity and Fecundity in the Rockfishes, *Sebastes* spp., a Review

LEWIS HALDORSON and MILTON LOVE

ABSTRACT—Literature was reviewed for data describing fecundity, maturity, and growth in the ovoviviparous genus Sebastes *(rockfishes). Assembled data were examined for patterns associated with geographic location and fish length. Rockfishes display great range in length at maturity (9-52 cm total length) and estimated fecundity at maturity (1,700-417,000 eggs or embryos). Within species, length at maturity usually increases at higher latitudes and tends to be greater for females than males. Among species, length at maturity of females is positively and significantly correlated with maximum length and with the ratio of fecundity at maturity to fecundity at maximum length. Fecundity of rockfishes is not notably lower than oviparous fishes such as snappers (Lutjanidae) and cods (Gadidae).*

Introduction

Sebastes (rockfishes) is a speciose genus with over 100 species that occupy diverse habitats from the intertidal zone to deep (>1,000 m) water. Within this depth range, they are typically associated with high-relief rocky substrates; however, species display great variation in substrate affinity, ranging from cryptic reef-dwellers to semipelagic schooling species. The eastern North Pacific is the distributional center for *Sebastes*, with over 50 species occurring from California through British Columbia (Eschmeyer and Herald, 1983). About 25 species occur in the western North Pacific (Masuda et al., 1984), four occur in the North Atlantic (Kendall, 1991) and at least one is found in the southern hemisphere off South America and South Africa (Chen, 1971).

Rockfishes are gonochoristic, with internal fertilization. Eggs incubate and embryos hatch in the ovaries, with subsequent extrusion of larvae. They have generally been regarded as classic examples of ovoviviparous fishes; however, recent studies have suggested that developing young use exogenous energy prior to birth (Boehlert and Yoklavich, 1984). Although females of many species of rockfishes release a single brood annually, some species produce multiple broods (MacGregor, 1970). Rockfishes are generally recognized as slow-growing (e.g., Archibald et al., 1981), with a suite of life history characteristics that places them in the K-selected group (Adams, 1980).

Reproductive parameters defining maturity schedules and fecundity are important life history characteristics. Cole (1954) explicitly identified mortality and reproductive variables as determinants of Darwinian fitness and established the paradigm that natural selection acts on a suite of life history characteristics to maximize fitness. Fishes have been used to analyze the accuracy of several life history models (e.g., Bell, 1980; Roff, 1984; Stearns and Koella, 1986). Fish-based data are useful because information on age at maturity, fecundity, and growth are available for a variety of species. The models all follow Cole (1954) in assuming that age at maturity, fecundity, growth, and mortality have coevolved to maximize Darwinian fitness. Observations that significant correlations exist among life history parameters (e.g., Adams, 1980; Pauly, 1980; Roff, 1981, 1984) suggest the assumption is correct.

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Our summary of information describes maturity and fecundity as functions of length. Fecundity descriptions should be regarded with caution due to a number of inherent problems. Inconsistent methodology in determination of egg or embryo number may introduce considerable meaningless variation. Additional measurement variation is introduced when estimating fecundity of multiple spawning species (Grimes, 1987). In rockfishes, fecundity measurements also are a function of development stage, as fecundity decreases from pre-fertilizaton to the late embryo stage (Kusakari, In press). Consequently, fecundity estimates should be viewed as approximations, especially in those cases where we have extended the length-fecundity function outside the range of original observations (e.g., estimates of fecundity at maximum length).

The objectives of this review are to assemble the available information on maturity and fecundity in rockfishes, to explore the assembled data for patterns associated with geographic distribution and fish length, and to determine whether patterns are consistent with life history models.

Methods

Data describing length at maturity (length where 50 percent were mature), fecundity, growth, maximum reported length (MRL), and length-weight relationships were assembled from published literature and a limited number of unpublished sources. To identify sources we used our personal bibliographic reference systems, two recent bibliographic summaries (Clay and Kenchington, 1986; Leet and Reilly, 1988), and ab-

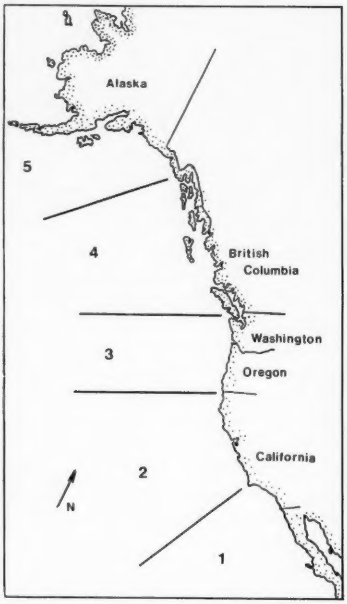

Figure 1.—Geographic areas assigned to rockfish reproductive data from eastern North Pacific species.

stracting journals. Data from the northeast Pacific were assigned to geographic areas (Fig. 1).

Some sources tabulated fecundity-length data for individual fish but provided no fit of data to a model (e.g., Phillips, 1964). In cases where the number of observations appeared adequate, we fit such data to the model $F = a(L^b)$, using a least-squares algorithm. Lengths in the various sources were reported as standard, fork, or total length. We standardized all length measures to total length, based on the regression formulae provided by Echeverria and Lenarz (1985). For those species not included in that source, we used the mean regression coefficients for all species tabulated therein.

We used primary reproductive data (fecundity and length at maturity) and auxiliary data (growth described by the von Bertalanffy model, MRL, length-weight relationships) to generate derived reproductive data including fecundity at maturity (i.e., at length where 50 percent are mature), fecundity at MRL, fecundity per gram weight at maturity, and fecundity per gram weight at MRL.

The effect of latitude on maturity was examined by comparing the reported length at maturity between geographic areas, moving from area 1 northward through area 4 (Fig. 1). To determine whether females tended to mature at smaller or larger lengths than males, we compared the length at maturity for the two sexes in all species, including reports from all geographic areas. Differences were scored between areas or between sexes only if they differed by 2 cm or more. Results were tested for significance with chi-square tests, under the null hypotheses that comparisons scored as different would be evenly distributed between directions (north or south) or sexes.

The effects of fish size (length) on reproduction were examined through two linear regressions. In the first, length at maturity of females was the dependent variable and maximum reported length the independent variable. In the second, we regressed the ratio—fecundity at maturity:fecundity at maximum size—against size at maturity. We also plotted the trajectory of fecundity for each species from the length of 50 percent maturity of females to the maximum reported size for the species, using the fecundity-length parameters selected as typical for each species.

Results

Eastern North Pacific Species

Data describing fecundity and maturity were collected for 45 rockfishes from 27 sources (Table 1). Estimates of length at maturity in more than one geographic area were available in 23 species. Fecundity estimates were usually limited to a single geographic zone. For analyses of reproductive characteristics among species, we used data that typified the fecundity and maturity for each species. If more than one source provided data on a particular parameter, we chose either the one from the geographic area nearest the center of distribution for that species, or the one with the most complete set of data. With few exceptions, data typifying a species are from a single area.

Length at maturity generally increased at the higher latitudes. Of 32 cases where female maturity could be compared between geographic areas, length at maturity in the northern area was greater in 20 cases, less in 4, and equal in 8 ($P<0.05$). In 30 cases where males were comparable, the length at maturity was greater in the north 21 times, less 5, and equal 4 ($P<0.05$). The only two species in which both males and females matured at shorter length in a more northerly area were *Sebastes jordani* and *S. levis*, compared in zones 1 and 2 (Fig. 1).

Females tend to be larger at maturity than males, as this occurred in 29 cases whereas males matured at greater size only 5 times ($P<0.01$). In 42 cases there was no difference between the sexes. Female length at maturity varied from 9 cm (*Sebastes dalli*) to 52 cm (*S. pinniger* and *S. ruberrimus*). The mean length at maturity was 31 cm for females and 29 cm for males.

Length at maturity is related to maximum size attained by a species. Linear regression of female length at maturity on maximum length was highly significant ($P<0.001$, Fig. 2).

Fecundity as a function of length varied among species (Table 1). The exponent in the power equation ranged from 2.80 (*Sebastes hopkinsi*) to 5.51 (*S. alutus*), with a mean of 4.10. Calculated fecundity at maturity varied from 1,700 in *S. dalli* to 417,000 in *S. paucispinis* (Table 2), with a mean of 124,000. Calculated fecundity at maximum length varied from 35,000 for *S. hopkins* to 5.6 million for *S. miniatus* (Table 2), with a mean of 1.1 million.

Fecundity at maturity as a proportion of fecundity at maximum length varied from 0.01 to 0.25, with a mean of 0.09, and appears to be a positive function of size. A regression of that proportion on length at maturity was significant ($p<0.05$, Fig. 3).

We used fecundity per gram of body weight (FGB) as an indicator of relative investment in reproduction. At sexual maturity FGB ranged from 70 in *Sebastes alutus* to 325 in *S. elongatus* (Table 2), with a mean of 183. At maximum length

Table 1.—Reproductive and other life history parameters for rockfishes. Areas correspond to those in Figure 1, S[1] (in parentheses following Area) identifies data source from list at bottom of table. All lengths are in total lengths (converted when necessary based on Echeverria and Lenarz (1985). Data include: Maximum reported length (MRL), asymptotic length in the von Bertalanffy equation (L), k in the von Bertalanffy equation (K), the exponent in the length-weight power equation (L-W B), the exponent in the fecundity-length power equation (FEC B), length at 50 percent maturity for females (F MAT) and males (M MAT). Values used to typify species are underlined.

Species	Area (S[1])	MRL	L	K	L-W B	FEC B	F MAT	M MAT
aleutianus	4(3,25)	97	57	0.050			47	45
alutus	2(2)	51					26	28
alutus	3(18)	51				6.334		
alutus	3(16)	51	51	0.091		7.325	36	31
alutus	4(16)	51	51	0.114		5.513	38	32
alutus	4(3,22)	51	45	0.126			37	36
alutus	5(15,17)	51			2.913	5.3	30	29
auriculatus	2(2)	52					31	31
auriculatus	3(11)	52				3.341		
aurora	2(2)	38					28	28
babcocki	2(2)	64					34	31
babcocki	4(4)	64					43	39
borealis	4(3)	91					47	47
brevispinis	4(3,22)	71	59	0.085			46	44
carnatus	2(2)	39					17	17
caurinus	2(2)	57					34	
caurinus	3(12)	57	46	0.160		4.957		
caurinus	3(11,19)	57			3.040	5.300		
chlorostictus	1(1)	50			3.163	4.971	22	22
chlorostictus	2(2)	50					28	27
chrysomelas	2(2)	39					15	16
ciliatus	4(7)	41	52				29	26
constellatus	1(1)	46	45	0.087	3.160	4.251	22	19
constellatus	2(2)	46					27	30
crameri	1(5)	76				5.059		
crameri	2(2)	76					27	27
crameri	3(3,22)	76	40	0.087			39	36
dalli	1(1)	25			3.215	4.098	9	9
diploproa	1(5)					4.705		
diploproa	2(2)						19	22
diploproa	3(20)	46	39	0.084				
diploproa	4(3)						28	27
elongatus	1(1)	38	37	0.098	3.128	3.739	19	18
elongatus	2(2)	38					23	23
elongatus	3(3)	38					24	24
entomelas	1(5)	53				4.892		
entomelas	1(1)	53			2.943	4.716	35	32
entomelas	2(2)	53					37	36
entomelas	3(8,9)	53				5.431	38	33
entomelas	4(3)	53					41	40
flavidus	1(5)	66				4.714		
flavidus	1(1)	66			2.822	4.816	36	32
flavidus	2(2)	66					36	35
flavidus	3(6,23)	66	57	0.163			46	42
flavidus	4(3,22)	66	50	0.186			43	41
flavidus	4(7)	66			3.151		43	44
goodei	1(5)	56				4.384		
goodei	1(1)	56			3.120	3.606	30	28
goodei	2(2,24)	56	56	0.180			34	31
goodei	3(6,24)	56	56	0.180			39	28
helvomaculatus	2(2)	33					23	22
helvomaculatus	4(3)	33					21	23
hopkinsi	1(1)	29	25		2.964	2.799	14	13
hopkinsi	2(2)	29					18	16
jordani	1(5,21)	30	35	0.211	3.152	3.306	16	16
	2(2)	30					14	14
levis	1(1)	94			3.093	3.154	43	44
levis	2(2)	94					32	32
maliger	4(7)	61					36	35
marinus (Atl.)	(26)	80					41	26
marinus	(27)	80				4.278	43	
melanops	2(2)	60					41	36
melanops	4(7)	60			3.286		41	42
melanostomus	1(1)	61			3.042		34	34
melanostomus	2(2)						35	33
miniatus	1(5)	76				5.686		
miniatus	1(1)	76			2.923	5.023	37	35
miniatus	2(2)	76					37	38
mystinus	2(10)	53			2.808		27	26
mystinus	2(2)	53					29	27
nebulosus	2(2)	43					27	27
ovalis	1(1)	56			3.137		25	24
ovalis	2(2)	56					28	28
paucispinis	1(5)	91				4.840		
paucispinis	1(1)	91			3.061	3.270	36	35
paucispinis	2(6,24)	91	92	0.11			50	47
paucispinis	2(2)	91					48	42
pinniger	1(5)	76				4.021		
pinniger	2(2)	76					44	40
pinniger	3(3,20)	76	70	0.118			52	42
pinniger	4(6,22)	76	54	0.139			51	40
proriger	4(3,22)	51	40	0.166			30	29
reedi	4(3,22)	58	46	0.125			39	38
rosaceus	1(1)	36			3.386	3.650	15	15
rosaceus	2(2)	36					20	20
rosenblatti	1(1)	48	58	0.053	3.106	4.375	28	30
ruberrimus	2(2)	91					40	40
ruberrimus	4(7,14)	91	67	0.049			52	57
rubrivinctus	2(2)						34	30
rufus	1(1)	51			3.1468	4.220	36	31
rufus	2(2)	51					34	31
saxicola	1(5)	39				3.214		
saxicola	1(1)	39	33	0.064	2.805	3.792	10	10
saxicola	2(2)	39					16	17
semicinctus	1(1)	25	18	0.370	2.938	3.916	11	11
serranoides	2(2,4)	61	52	0.18	3.063	4.619	34	32
variegatus	4(3)	32					23	24
zacentrus	4(3,22)	33	36	0.095			25	24

[1]Sources: 1 = Love et al., 1990; 2 = Wyllie Echeverria, 1987; 3 = Westrheim, 1975; 4 = Love and Westphal, 1981; 5 = Phillips, 1964; 6 = Gunderson et al., 1980, 7 = Rosenthal et al., 1982; 8 = Boehlert et al., 1982; 9 = Barss and Wyllie Echeverria, 1987; 10 = Miller and Geibel, 1973; 11 = DeLacy et al., 1964; 12 = Washington et al., 1978; 13 = Paraketsov, 1963; 14 = O'Connell, personal commun.; 15 = Chikuni, 1975; 16 = Gunderson, 1977; 17 = Lisovenko, 1965; 18 = Westrheim, 1958; 19 = Patten 1973; 20 = Boehlert and Kappenman, 1980; 21 = Lenarz, 1980; 22 = Archibald et al., 1981; 23 = Fraidenburg, 1980; 24 = Wilkins, 1980; 25 = Nelson and Quinn, 1987; 26 = Ni and Sandeman, 1984; 27 = Raitt and Hall, 1967.

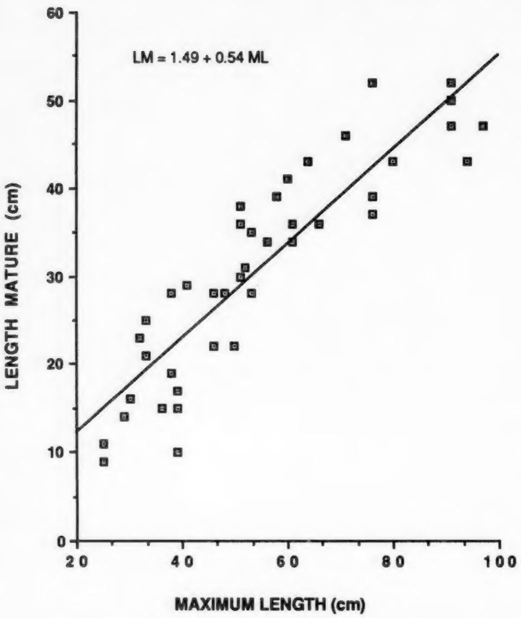

Figure 2.—Linear regression of length at maturity on maximum reported length for 42 *Sebastes* species.

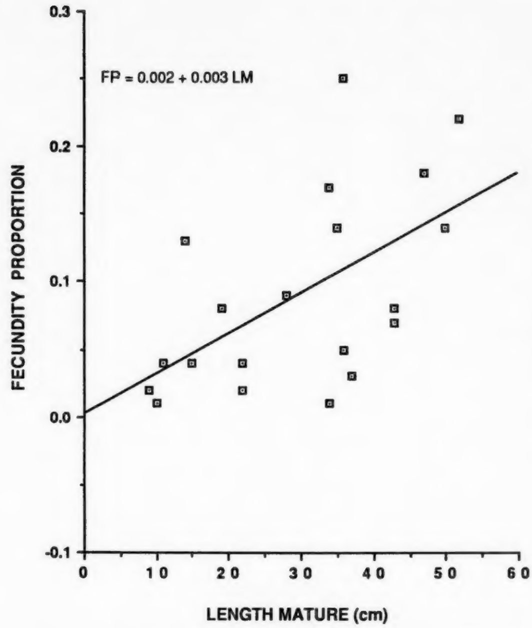

Figure 3.—Linear regression of fecundity at maturity/fecundity at maximum length on length at maturity for 20 *Sebastes* species.

FGB ranged from 163 in *S. alutus* to 826 in *S. miniatus*, with a mean of 416. A regression of FGB on maximum length was not significant.

We plotted fecundity trajectories from fecundity at maturity to fecundity at maximum size (Fig. 4). The trajectories define an envelope of fecundity-at-length values for rockfishes. The species with data points outside the envelope are *Sebastes alutus* and *S. marinus*.

Western North Pacific Species

We located data describing fecundity for six species of western North Pacific rockfishes: *Sebastes inermis*, *S. pachycephalus*, *S. schlegeli*, *S. steindachneri*, *S. taczanowski*, and *S. vulpes* (Table 3). Although we were unable to locate data sets suitable for assessing maturity (i.e., with indications of lengths of immature fish), the minimum length of females reported as mature in fecundity data allowed a very tentative indication of length at maturity, which ranged from 8 cm in *S. pachycephalus* to 34 cm in *S. schlegeli*.

Fecundity of western North Pacific rockfishes was low (Table 3), but typical of small species. When minimum and maximum sizes of fish in those studies

Table 2.—Fecundity-related parameters for rockfish species, including geographic area of data source (Area, from Figure 1), calculated fecundity at length of 50 percent maturity (FMAT, in 1,000's), calculated fecundity at maximum reported length (FMAX, in 1,000's), ratio of fecundity at maturity to maximum fecundity (FRAT), fecundity per gram of body weight at maturity (FGBMAT), fecundity per gram of body at maximum size (FGBMAX), and ratio of FGBMAT to FGBMAX (FGBRAT). Data used to generate parameters are underlined in Table 1.

Species	Area	FMAT	FMAX	FRAT	FBGMAT	FGBMAX	FGBRAT
alutus	4	40	227	0.18	70	163	0.43
chlorostictus	1	24	1395	0.02	148	651	0.23
constellatus	1	34	772	0.04	198	445	0.44
dalli	1	2	113	0.02	155	383	0.40
elongatus	1	26	344	0.08	325	497	0.65
entomelas	3	134	948	0.14	233	487	0.48
flavidus	1,3	125	1146	0.11	177	593	0.30
goodei	1,2	64	384	0.17	140	178	0.81
hopkinsi	1	7	35	0.13	187	166	1.13
levis	1	241	2842	0.08	212	222	0.95
miniatus	1	151	5602	0.03	182	826	0.22
paucispinis	1,2	417	2954	0.14	324	367	0.88
pinniger	1,3	85	389	0.22			
rosaceus	1	15	354	0.04	291	367	0.79
rosenblatti	1	47	499	0.09	136	271	0.50
rufus	1	111	482	0.25	163	235	0.69
saxicola	1	3	315	0.01	215	825	0.26
semicinctus	1	4	86	0.04	199	494	0.40
serranoides	2	71	1058	0.07	130	324	0.40

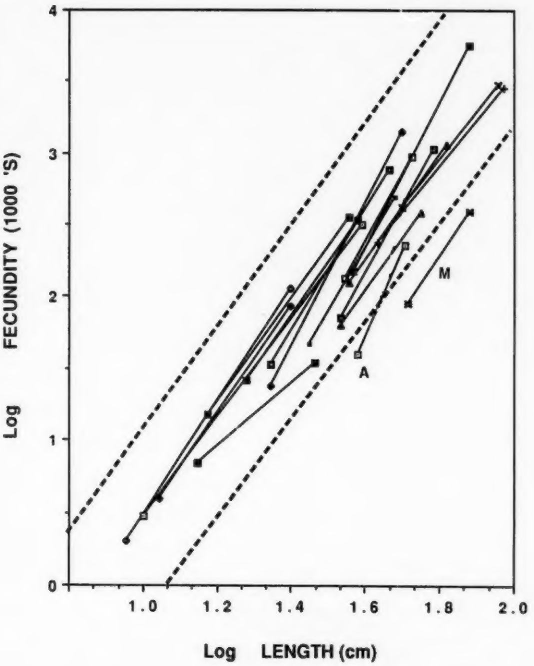

Figure 4.—Fecundity trajectories—the line connecting fecundity at maturity with fecundity at maximum length—plotted against length for 20 *Sebastes* species. The dashed lines represent an fecundity-length envelope for rockfish species fitted by eye. A = *Sebastes alutus*, M = *S. marinus*.

Table 3.—Summary of fecundity and derived maturity data for *Sebastes* sp. from the western North Pacific. Estimates include parameters of the fecundity-length power equation ($F = aL^b$): a = FEC A, b = FEC B; length (cm) of smallest fish in fecundity data set (MINL); length of largest fish in fecundity data set (MAXL); fecundity (1,000 eggs) of smallest fish in fecundity data set (MINF); fecundity (1,000 eggs) of largest fish in fecundity data set (MAXF); and number of fish in fecundity data set (N). Sources of data[1] are indicated in parentheses.

Species	FEC A	FEC B	MINL	MAXL	MINF	MAXF	N
inermis (1[1])	0.119	5.56	15.8	23.4	4	62	25
pachycephalus (2)	0.016	3.639	7.8	17.5	1.5	10	43
schlegeli (3)			33.8	60.0	44	780	116
steindachneri (4)			26.9	31.4	112	184	4
taczanowski (4)	0.159	2.858	10.8	32.5	8	111	18
vulpes (4)			25.5	32.6	12	151	7

[1]Sources: 1 = Mio, 1960; 2 = Shiokawa, 1962; 3 = Kusakari, In press; 4 = Sasaki, 1975.

were plotted with their associated fecundity estimates, the fecundity trajectories fell within the envelope defined by eastern North Pacific rockfishes. Futhermore, their lengths at maturity and fecundities are similar to those of eastern North Pacific species that mature at small sizes (e.g., *Sebastes dalli*, *S. saxicola*, *S. semicinctus*)

North Atlantic Species

In the western North Atlantic, there apparently are three *Sebastes* species, *S. marinus*, *S. mentella*, and *S. fasciatus*, although considerable taxonomic confusion has been associated with the latter two. Ni and Sandeman (1984) examined historical data on length at maturity in western North Atlantic populations of the three species. Length at maturity for *S. marinus* was 21-26 cm in males and 38-41 cm in females. The two other species were combined as the beaked redfishes, in which males matured at 16-29 cm and females at 24-43 cm.

Raitt and Hall (1967) reported length at maturity for female *S. marinus* from the eastern North Atlantic as 42 cm and 43 cm for populations near Iceland and the Faroe Islands, respectively. They also reported very similar fecundity estimates for those populations (included in Table 1). The fecundity trajectory from maturity to MRL is to the right of the envelope of fecundity trajectories based on eastern North Pacific species (Fig. 4).

Discussion

Increased maternal investment in progeny through viviparity or ovoviviparity is often assumed to result in decreased fecundity. Comparison of rockfish fecundity with oviparous fish taxa may indicate if total fecundity is indeed lower in rockfishes as a result of their ovoviviparity. Grimes (1987) compiled fecundity estimates for snappers (Lutjanidae), a tropical family generally similar to rockfishes in size and shape. Mean FGB at maximum length for 13 snapper species was 731 (Grimes, 1987); in our compilation of 18 rockfish species, the mean FGB at maximum length was 416. His mean maximum fecundity for the 13 snapper species was 2.2 million at a mean maximum length of 55 cm. For rockfishes the mean maximum length was slightly lower at 52 cm; mean maximum fecundity was 1.1 million, half the value for snappers. However, there was considerable overlap in the ranges of fecundity parameters in rockfishes and snappers. Hislop (1984) summarized fecundity data for four gadoid species from the North Sea and estimated FGB for cod, *Gadus morhua*, and haddock, *Melanogrammus aeglefinus*, at 475 and 550, respectively. Those values are very similar to rockfishes, as are estimates of total fecundity at similar lengths. Rockfish fecundity apparently is lower than some comparable oviparous fishes, but the difference is not dramatic.

Increased length at maturity at higher latitudes is relatively common in eastern North Pacific rockfishes and has also been reported for rockfishes in the eastern North Atlantic (Ni and Sandeman, 1984). Increased size at maturity may be due to an extension in the juvenile period of northerly populations, to faster growth, or a combination of the two. However, few data are available for assessment of geographic variation in growth, and there is no indication of a general pattern. In the eastern North Pacific, *Sebastes pinniger* do not display geographic variation in

growth, whereas *S. diploproa* grow faster in the north (Boehlert and Kappenman, 1980). Love (1978) also reported faster growth by *S. serranoides* to the north. Conversely, Westrheim and Harling (1975) reported a general trend of faster growth in southerly populations in seven out of eight rockfish species. Growth variation may be even more complex—Gunderson (1977) found male *S. alutus* grew faster in a southerly population, whereas females grew faster in the north. Given the lack of clear latitudinal trend in intraspecific growth, increased length at maturity in northern populations is likely due to delayed maturity.

There are several previous reports that female rockfishes mature at larger sizes than males of the same species. Ni and Sandeman (1984) found that females of *Sebastes marinus*, *S. mentella* and *S. fasciatus* all mature at larger sizes than males. Among 17 species of eastern North Pacific rockfishes, Wyllie Echeverria (1987) found that females matured at similar or larger sizes than males, and at older ages. Love et al. (1990) reported that in 7 out of 17 species, females matured at larger sizes than males.

Maturity at larger size in females could result from either later maturity or faster growth. Females have been reported to grow faster than males in *Sebastes marinus* (Kelly and Wolf, 1959), *S. alutus* (Westrheim, 1973), *S. flavidus* (Six and Horton, 1977, Fraidenburg 1980), *S. melanops* (Six and Horton, 1977), *S. pinniger* and *S. diploproa* (Boehlert and Kappenman, 1980), *S. constellatus*, *S. elongatus*, *S. hopkinsi*, *S. ovalis*, *S. rosenblatti*, *S. saxicola*, and *S. semicinctus* (Love et al., 1990). Although Wyllie Echeverria (1987) found older ages at maturity in females of several species, the widespread occurrence of faster growth in female rockfishes suggests that growth differences are a major factor contributing to larger size at maturity in females.

Among life history models, Bell's (1980) model appears generally consistent with a variety of life history patterns observed in fishes and other groups, and is based on an assumption that mortality rate decreases with increasing size. The model predicts that optimal size (or age) at maturity will occur when the rate of increase in fecundity equals the rate of decrease in survival. In other words, if juvenile mortality increases, relative to adult mortality, the optimum size of maturity increases; conversely, if adult mortality increases, relative to juveniles, the size at maturity should decrease. These patterns are consistent with the results of experimental studies (e.g., Barclay and Gregory, 1981), observations of a variety of wild populations (summarized in Stearns, 1977), and natural experiments comparing interpopulation variation of life histories in mosquitofish (*Gambusia*) in Hawaii (Stearns, 1983), guppies in Trinidad (Reznick, 1982) and shad in the eastern North Atlantic (Leggett and Carscadden 1978). Bell's (1980) model also leads to the prediction that females should mature later and/or at larger sizes than males; this was observed in Healey's (1986) analyses of salmon populations and is true for many rockfish species we reviewed.

If the relationship between adult and juvenile mortality determines size at maturity, the observed trend in maturity at smaller size in southern populations of rockfishes suggests that, relative to juveniles, adult mortality is higher in the south than in the north. This is not consistent with the suggestion by Boehlert and Kappenman (1980) that frequent episodes of low survival of larvae (due to offshore transport) has resulted in increased reproductive effort (and as a result, lower growth) in southern populations of *S. diploproa*. If southern populations experience increased larval mortality, Bell's model predicts that they should mature later, rather than earlier, relative to northern populations. Embiotocids, with no pelagic life stages, appear to be similar to rockfishes in having delayed maturity to the north (DeMartini et al., 1983). A possible mechanism might involve geographic differences in size-specific predation rates (Law, 1979).

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